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Electromagnetic Fields Characteristics From Overhead Lines, Underground Cables and Transformers Determined Using Finite Element Method

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Abstract— **Magnetic fields may have detrimental potential health effects and can be in our homes or workplaces. This study focuses on magnetics fields only as it can vary. This study is to simulate and analyse magnetic fields radiations in the vicinity of 132 kV overhead power lines for two cases; with straight conductors and with conductors sags, 11 kV triangular straight underground cable for two cases; as 185 mm^2 , and 120 mm^2 cross-sectional area at 0.9 m in depth, and for 1000, 1600, and 2000 kVA transformers determined using finite element method via ANSYS Maxwell. Also, to compare the results with the safety limits as defined in recent international standards. The results are showing safe exposure level of magnetic fields as long as the distance is respected and It is advisable that safety precautions should be taken to prevent prolong exposure of electromagnetic fields (EMF) radiation to human body.**

*Keywords——**Electromagnetic fields, magnetic field, negative health effects, extremely low-frequency, overhead power lines, underground cabler, transformers,***

I. INTRODUCTION

Electricity has become critical in our daily life especially in modern and industrial cities as it does make our life easier. Consequently, electricity demand keeps on rising, towns keep on expanding and become closer to power systems especially in crowded population regions. Many electrical systems involving either apparatus or conductors are available around us, forming network to meet the increasing electricity demand and to transmit energy from generation stations to the load centers. As a result, people are getting exposed to electromagnetic radiation without them being realise since it is invisible and silent.

EMF are combinations of invisible electric and magnetic fields of force collectively where electric fields are proportional to electric charges, and magnetic fields are proportional to electric currents. Magnetic field radiation can be found in different countless technologies but in electrical power systems it is considered as extremely low frequency (ELF) because their frequency normally does not exceed 300 Hz, man-made, non-ionize, and has no thermal effect. Magnetic fields cannot be shield completely while eelectric fields can be screened by objects such as buildings, trees, and wall.

II. LITERATURE REVIEW

A. EMFs safety exposures limits

It can be seen that the limits set by ICNIRP 2010 and IEEE 2019 are not time average based and had been set in the ranges (200-1000 μT) and (0.9-3mT) respectively which has quite a huge different value. IEEE 2019 updated the limits based on the updates in scientific knowledge and uncertainties considerations calculated.[1], [2]

B. Parameters that affect magnetic fields

1) Phase current magnitude

The most obvious parameter which affects the magnitude of the magnetic field is the magnitude of currents in each phase for either zero, positive or negative sequence.

2) Conductors configuration

Overhead three-phase transmission lines arrangement can be horizontal, vertical, circular, ellipse, or mixed arrangements while in underground cables can be flat, triangle or square. For transformers, as star or delta connection for each side. Conductor materials, cross-section area, phasing, straight lines, or with sags also influence the magnitude of magnetic fields.

3) Conductor height, depth ,and spacing

The height of the conductor influences the magnetic field strength at the surface level. The higher the conductors, the lower magnetic field exposure to the ground level. This is true for the case of transmission lines. Meanwhile, for underground cables, the more the depth of buried cable, then the lower is the magnetic field which can found at the surface level.

The spacing between the phases is also a factor that affects the magnetic field magnitude. The closer the phases in a circuit, the lower magnetic field produced as they can cancel out each other. For underground cables as based on some studies, for three phase cable triangular configuration has the lowest magnetic field followed by the square and then the vertical configuration [3]–[6].

C. Biological effect of EMF

Studies have shown that health risk potentials for humans from EMF can be categorised into long and short term health effects. Long term health effects are about epidemiological diseases such as leukemia, brain cancer, lung and breast tumors, genotoxicity, infertility, birth defects, and Alzheimer's disease. In contrast, the short term health effects can be headache, fatigue, cataracts, nausea, chest pain, hypersensitivity, and sleep disturbances. Other adverse effects can be rapidly moving charges within the body, such as in blood flow, and cardiac excitation which results in small change in heartbeat. Enhanced tumors in skin, liver, and brain [1], [7] .

III. METHODOLOGY

The methods used to fulfill the aims of the study are generally covered in this section. Secondary data were gathered

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mainly to form the geometry models. ANSYS Maxwell software features are used generally. Once the models were designed based on required materials, different value of current applied. Then, magnetic field data loading are set to be at one meter high. lastly, magnetic fields were and compared with the international safety limits.

1) Design of overhead power lines

The simulation work started with finding complete geometry data for 132 kV double circuit overhead power transmission lines using secondary data involving parameters such as conductor's dimensions to the tower and surface also the cross-sectional area of the conductors. For the currents, it is assumed that both circuit lines having the same currents and no abnormal power quality issues but different load rating cases applied.

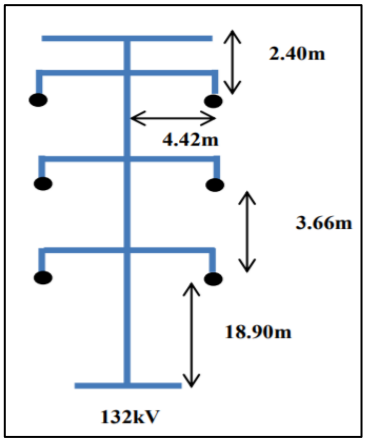

Figure 1 Dimensions of 132 kV double circuit overhead lines [8]

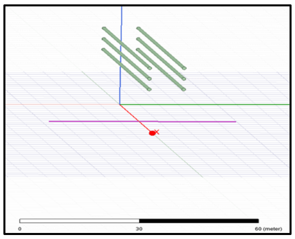

Figure 2 132 kV geometry for overhead straight lines

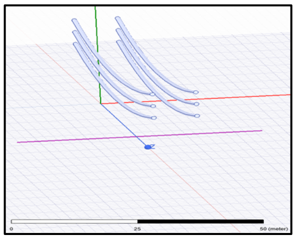

Figure 3 132 kV geometry with sagging lines

TABLE I Type and size of phase conductor

Voltage (kV)	type	Qty/Bundle	Currents (A)
132	Batang 300 (mm^2)	1	10, and Maximum current allowed 616.72

2) Design of underground cables

The first step was to find complete secondary datasheet set for 11 kV triangular cables for different cross-sections that are 185 mm^2 and 120 mm^2. Single cable models contain three phase compacted copper were used. Insulation material used is PVC while XLPE not included as it is not found in the software library. Different semiconductor lyres were used. It functions to screen the conductors and insulator. Copper was used as metallic screen tape. The design structure used for 3*185 mm^2 cross sectional area cable are shown in Figure 4. The simulation is for different balance current cases and including maximum allowable currents at 0.9 m in depth while loading the data at one meter high

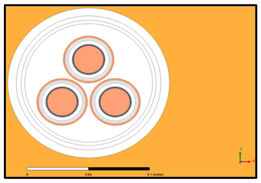

Figure 4 3*185 mm^2 triangular 11 kV cable

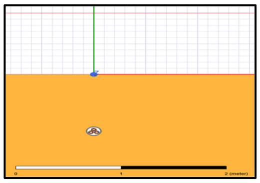

Figure 5 Shows the line of loading the data

3) Design of transformers

In order to obtain the magnetic fields from different transformers, then different core with windings are designed and fitted in it desired places based on the metal covers dimensions that are imported from official secondary three dimensional files for different transformer rating such as 1000, 1600, and 2000 kVA. The core of the transformer is from ANSYS Maxwell library and material used is ferromagnetic steel. Current was injected to the windings of each phase. Magnetic field data was loaded at one meter high from both directions; the right and left side twice for every transformer starting from 20 mm to 0.5 m for near fields, and from 1 m to 5 m for far fields. The currents tested are calculated based on full load current condition. Other balance current cases were also examined. Figure 6 demonstrate how the cores are scaled using official secondary data for the metal cover while Figure 7 illustrates the final design and windings orientations after removing the metal cover.

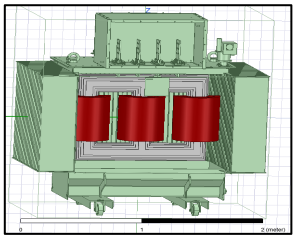

Figure 6 Back side view

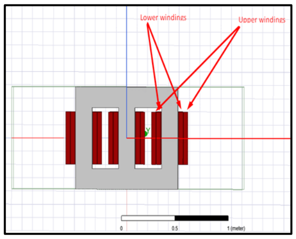

Figure 7 The core and the windings of the transformer

IV. RESULTS AND DISCUSSIONS

1) Magnetic fields from 132 kV overhead double circit lines

The geometries are modelled considering actual secondary data as conductors, including configurations, phasing, and clearance distance. For each model, different load current including the maximum allowable current limit were applied and the results were analysed.

a) 132 kV straight lines

Figure 8 illustrates that magnetic fields has a constant magnitude value along the distance between the towers. For maximum load current 616.72 A, the average simulated magnetic field is 38 μT

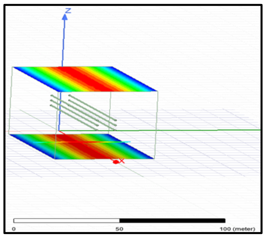

Figure 8 Shows content magnetic fields along the lines

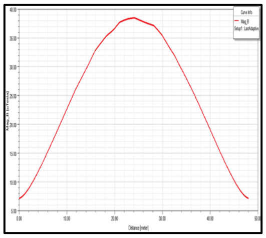

Figure 9 Lateral distance plot for straight lines max current applied

b) *132 kV with sags*

Solidworks software used in order to build power lines containing sags then imported to ANSYS Maxwell software for finite element method simulation. It can be seen as in Figure 10, that there is no more straight lines of magnetic field concentration. For maximum load current, 616.72 A is applied for both circuits and lines and the average simulated magnetic field is 51.27 μT.

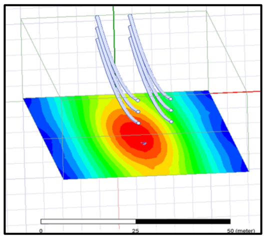

Figure 10 Magnetic field concentration

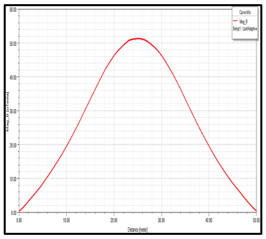

Figure 11 Shows all determined findings once with the sags model

TABLE II Magnetic fields from overhead power lines

Magnetic field reading in (**μT**)				
Current simulation work			Based on an published article results in [8]	
Currents **(A)**	Straight lines	With sags	Measured	simulated
10	0.63	0.8304	0.688	0.637
616.72	38	51.2738		

TABLE II shows that comparing the result of current study to the previous research, it can be seen that the difference is about 10%. It can be concluded that the magnetic fields from power lines with and without sags are still by far under the safety limits set by IEEE 2019 and ICNIRP2010.

2) *Magnetic fields from underground cables*

The geometry for triangular underground cables were modeled using secondary data for 11 kV cables of different cross-section area that are 185 mm^2 and 120 mm^2. The simulations were done for different currents value up to the maximum allowable currents at 0.9 m in depth. The applied current was calculated based on Ampere's Law. For this simulation, it is assumed that the conductors are placed close to each other and having the same current load in each phase. The modeled underground cables considers 20 m clearance distance. It is acceptable distance to load the magmatic field data

*11 kV underground cable of 3*185 mm^2 and 120 mm^2*

For 185 mm^2 cable a maximum allowable current of 361 A applied based on secondary data. Figure 12 indicates the simulated magnetic field is 97.6598 μT**.** The results show an increase of the magnetic field magnitude from 4.5442 μT up to 97.6598 μT once varying the current from 16.83 A to 361 A. while for 120 mm^2 cable maximum allowable current of 282 A applied. Figure 13 indicates the simulated magnetic field is of 44.89 μT

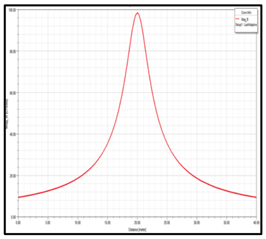

Figure 12 361 A max current examined

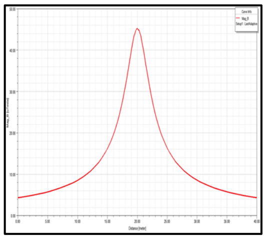

Figure 13 Magnetic fields for smaller cable at max currents allowed

TABLE III Magnetic fields findings for the cables in (μT)

Current work			Results of previous studies [5]	
Cross sectional area	Applied current **(A)**	Simulated **(μT)**	Measured **(μT)**	Calculated **(μT)**
120 mm^2	8.415	1.3374	1.87	3.21
	282	44.89		
185 mm^2	16.83	4.5442	3.74	3.91
	361	97.6598		

TABLE III shows that the result of this study is more than 10% variation when compared with the results of [5] It is that the typical geometry data as for the exact materials or layers thickness used in the published article are not available. The table shows quite a significant magnetic field. The table indicates that smaller cross-sectional area cables are capable to handle less current compared to bigger cross section cables resulting lesser magnetic fields. It also shows once applying the same current for both cross section cables then 120 mm^2 cable is still resulting lesser magnetic fields.

3) *Magnetic fields from transformers*

Transformer models consist of core and windings from library of ANSYS Maxwell software were used. The sizing is referred to external secondary files for transformers metal covers loading them independently to Maxwell software. Maximizing the core and the size of the windings through the scaling tool in Maxwell software to fit in as shown in Figure 6. Further, The designed models allowed injection of both upper and lower currents in the windings of each phase . The metal cover was removed and desired materials such as ferromagnetic steel and conductive copper were applied to the core and windings as in Figure 7. Magnetic field data loading are from two directions the right and the left sides of the transformers for both far and near fields at one meter height. The far fields were set to be emulating from 1 m to 5 m while near fields were set to be emulating from 20 mm to 0.5 m. The currents examined are calculated based on full load current condition also for at 35 % referring to full load current as indicated in TABLE IV.

1000, 1600 ,and 2000 kVA transformers

For 2000 kVA transformer full load currents of 2816.34 A for the lower windings while 57.73 A applied for the upper windings. The magnetic fields obtained are shown in the Figure 14to Figure 15 for both directions right and left side and loaded for one meter high. a strength magnitude of 108.80 μT on the right and a magnitude of 110.50 μT for the left side but near field loaded from the 20 mm up to 0.5 m. The magnetic fields obtained are shown in Figure 16 to Figure 17 varies between 4.4941 mT to 1350 μT on the right and left side. The increase of the magnetic fields when compared to 1000 kVA and 1600 kVA transformers is due to the increase of currents.

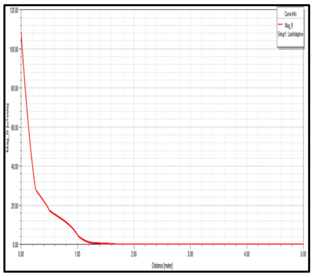

Figure 14 Left side magnetic field for far field

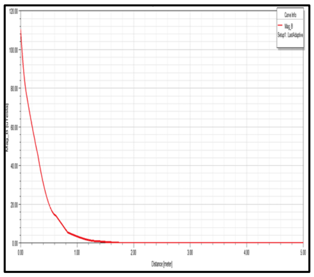

Figure 15 Right side magnetic field for far field

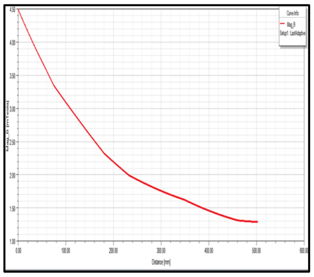

Figure 16 Left side magnetic field for near field

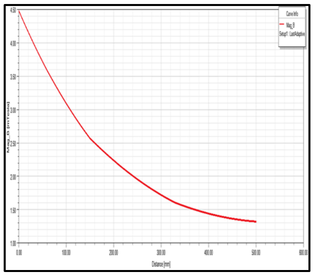

Figure 17 Right side magnetic field for near field

TABLE IV The Findings for transformers magnetic fields

Rating	Currents for lower windings **(A)**	Currents for upper windings **(A)**	Far magnetic fields from one to five meter in $\boldsymbol{\mu T}$		Near magnetic fields from 20 mm to 0.5 m in $\boldsymbol{mT}$	
			Left	Right	Left	Right
1000 kVA	492.86	10.101	16.3811	11.8563	0.83 to 0.19	0.89 to 0.19
	Max currents (1408.17)	Max currents (28.86)	46.9	34.02	2.5 to 0.56	2.5 to 0.56
1600 kVA	788.57	16.163	31.1193	33.68	1.30 to 0.35	1.30 to 0.35
	Max currents (2253.07)	Max currents (46.18)	91.7240	96.3617	3.7 to 1.009	3.7 to 1.01
2000 kVA	985.719	20.2055	44.9134	41.3086	1.59 to 0.462	1.5 to 0.45
	Max currents (2816.34)	Max currents (57.73)	110.50	108.80	4.49 to 1.32	4.4 to 1.2

TABLE IV shows a small variation of magnetic fields between each direction that could be due to not positioning the lines for loading the data as accurately as desired. The table shows bigger transformers handles more current for both primary and secondary windings. It also shows that near fields normally can have higher magnetic field in mili tesla compared to far fields.

V. CONCLUSION

Overhead power lines are having more clearance distance which result magnetic fields to be much lesser as compared to transformers or underground cables for the receivers. The literal plots showing that overhead power lines having slow increase and decrease characteristics while underground cables have rapid increase and decrease as the conductors are closer. For transformer case near fields and far fields are found within the acceptable safe limits with a decrease in magnetic field once to increase the distance.The work shows the magnetic field and electric field values in the vicinity of double circuit overhead power lines, 11 kV triangular underground cables and the different transformers are within the allowable range and limits set by ICNIRP 2010 and IEEE 2019 but as long as safety precautions considered as ROW for overhead power lines, the suitable depth of the cables, and fences for transformers so nobody meets the minimum clearances.

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