Measurements of Electromagnetic Radiations Generated by 11kv Underground Distribution Power Cables

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Abstract

Underground power cables are usually used to transfer electric power from distribution stations to the consumer, especially in densely populated areas in which the overhead lines cannot be used. During the process of energy transfer occurring some phenomena such as high temperature of the cable as a result of the losses, as well as the formation of electromagnetic fields around the cable. The aim of this research is to investigate the levels of electromagnetic fields generated by 11kv underground power cable. Research has been conducted in two ways, mathematical calculations and practical measurements. Results show that the mathematical calculations and practical measurements are approximately identical. The safe and unsafe zones from the underground power cable have been determined by comparison of these results with reference values established by the World Health Organization. These results may consider as an important data for the categorization of underground distribution power cables as well as individual sources of EMF to reduce exposure to such fields in order to avoid its negative health effects on human health.

Keywords: Underground cables, Human exposure to electromagnetic fields

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حساب الإشعاعات الكهرومغناطيسية المنبعثة من خطوط نقل القدرة الكهربائية11 كيلو فولت الممتدة تحت سطح الأرض

الخلاصة

تستخدم قابلوات القدرة تحت الأرض عادة في نقل الطاقة الكهربائية من محطات التوزيع الى المستهلك وخاصة في المناطق الكثيفة بالسكان والتى يتعذر فيها استخدام الخطوط الهوائية . أثناء عملية نقل الطاقة تحدث بعض الظواهر مثل إرتفاع درجة حرارة القابلو نتيجة للمفاقيد وكذلك هبوط الجهد وتوليد المجالات الكهرومغناطيسية حول القابلو. الهدف من هذا البحث هو حساب مستويات المجالات الكهرومغناطيسية المنبعثة من قابلوات التوزيع تحت الأرض. تم اجراء البحث بطريقتين: الحسابات النظرية والقياسات العملية .نتائج البحث اظهرت ان القياسات العملية متطابقة تقريبا مع الحسابات الرياضية. تم تحديد المناطق الآمنة وغير الآمنة من قابلوات الكهرباء تحت الارض من خلال المقارنة بين هذه النتائج مع القيم المرجعية التي وضعتها منظمة الصحة العالمية. ان هذه النتائج قد تعتبر من البيانات الهامة بالنسبة لتصنيف قابلوات القدرة الكهربائية تحت الارض كمصدر من مصادر انبعاث المجالات الكهرومغناطيسية للحد من التعرض لهذه المجالات من أجل تجنب آثارها الصحية السلبية على صحة الإنسان.

الكلمات الدالة: قابلوات نقل القدرة الكهربائية ات تحت الارض ، التعرض البشري للمجالات الكهرومغناطيسية.

ICNIRP :The International Commission on Non Ionizing Radiation Protection
NCI : National Cancer Institute.

Fields over 0.2 uT can be found in many houses due to such underground cables. These are usually due to what are called "net" currents. These are "stray" currents either flowing through the earth, or more usually through the wrong piece of cable or metal pipe work[5]. Another common cause of elevated field levels is undetected faults in internal building wiring. Appliances in the house continue to work correctly, but cause high magnetic fields throughout large areas of the house[6].Houses or ground floor or basement flats, with very small or no front garden, may have high magnetic fields in their front rooms from distribution cables running underneath the pavement[7] .

One of the main characteristics of the electromagnetic wave is its frequency (f) and wave length (λ) .The electromagnetic spectrum is the range of all possible frequencies of electromagnetic radiation. It extends from low frequencies used for modern radio communication to gamma radiation at the short-wavelength (high-frequency) end, thereby covering wavelengths from thousands of kilometers down to a fraction of the size of an atom. [8]

Electromagnetic radiation can be classified into two types: ionizing radiation and non-ionizing radiation, based on its capability of ionizing atoms and breaking chemical bonds. Ultraviolet and higher frequencies, such as X-rays or gamma rays are ionizing, and these pose their own special hazards [9]. Non-Ionizing Radiation ranging from the lowest outskirts of ultraviolet, through visual and infrared to radio frequencies, does not have the intensity

List of abbreviations
EMF: Electromagnetic field
EHS: Electrical hypersensitivity

Introduction

Nowadays, a multi-line power system is present in our neighborhood to satisfy increasing need for electric power. To distribute power from the power plant to the load center, it will be required a network starting from the transmission line until the consumer, so that in the vicinity of the transmission line and distribution network it will be found a strong electromagnetic field caused by currents that are drawn by their conductors [1]. So, during the past 20 years the general public has become increasingly concerned about potential adverse health effects of exposure to electric and magnetic fields at extremely low frequencies (50Hz).Such exposures arise mainly from the transmission and use of electrical energy at homes and work places [2].

Undergrounding refers to the replacement of overhead cables providing electrical power, with underground cables. This is typically performed for aesthetic purposes but increases the costs of electric power transmission and distribution. radiation usually defined as the expansion of energy through space, so the concept of electromagnetic Underground cables can transmit power across densely populated or areas where land is costly or environmentally sensitive. [3]
The electric fields from underground cables will be zero as they are screened by earth, concrete, sand etc. The magnetic fields are very high near to the cable, higher than from overhead cables because they are closer to human. They fall off more rapidly than the fields from overhead wires, because the cables are closer together and cancel out each other's effects more quickly[4].

- A much acclaimed USA National Cancer Institute (NCI) study by Linet et al, was published in July 1997. Although some claimed that this was a "negative" study, it did find an association between childhood leukemia and measured magnetic field levels very much in line with earlier studies: an increase in risk of about 1.4 times over 300 nT (0.3 µT), rising to a six-fold increase between 0.4 and 0.5 µT [13].
- The weight of evidence does link power lines and electricity EMFs with childhood leukemia,in a number of studies, with brain tumors.In 1998 a working group of the National Institute of Environmental Health Sciences classified power frequency EMFs as a "probable human carcinogen" [14].
- In June 1999 a team, led by Dr Lois Green, at the University of Toronto and the Hospital for Sick Children reported their findings that children with the highest exposures to EMFs were 4.5 times more likely to develop leukemia than those with the lowest exposures [15].
- In Denver, Colorado (2002), a study conducted by electrical engineers and epidemiologist reported that the risk of children dying from cancer was four times higher if they lived near high voltage/high current electrical lines than those who did not live near high current lines. The incidence of cancer was directly related to the intensity of electromagnetic fields (EMF) in the living area of the homes of victims who died from cancer. Electric current was followed from the utility service drop--hot, and neutral wires grounded to the water lines and EMF was related to current on the needed to directly damage biological tissues but, if sufficiently strong at frequencies over 100kHz, can significantly raise body temperature (thermal effect, the primary acute effect at frequencies higher than (10MHz), or induce currents causing neurological effects at frequencies bellow 100kHz [10].

Literature review

As a direct response to public concern, some major studies with multiple contributors with diverse expertise have been published recently on the health effects of low frequency electric and magnetic fields as follows:

- One of the strongest studies is the 1992 Swedish paper by Feychting & Ahlbom. It investigated 436,503 people who had lived within 300 meters of a high voltage power line, and indicated a dose-response relationship with childhood leukaemia. It showed no effect below 0.1 µT, a doubling in relative risk by 0.2 µT , although there were no cases between 0.2 and 0.3 µT, a tripling over 0.35 µT (micro Tesla)[11].
- The US National Research Council - National Academy of Sciences issued a report entitled "Possible Health Effects of Exposure to Residential Electric and Magnetic Fields" . The most important aspect of this report is that it does establish and agree that even under the strictest possible standards of proof, there is a reliable, though low, statistical association between power lines and at least one form of cancer (childhood leukemia).

  This fact in itself shows that we need to do more to find out why this relationship exists, and take prudent avoidance action in the meantime[12].

Methodology

Measurements of electromagnetic fields of underground cables are conducted in the following tree steps:

- Mathematical calculations
- Practical measurements
- Comparison the results with the international limit guidelines references.

1. Mathematical calculations

In the underground cable, electric field is screened by the cable sheath so would be eliminated above it. While Magnetic field is determined by the current, which changes in strength over time as the demand for electricity fluctuate. The magnetic field is strongest close to the cable and rapidly reduces further away from it.

We can determine the magnetic field generated from steady currents by using the *Biot-Savart law* [21] as follows:

$$\mathbf{B}(\mathbf{r}) = \frac{\mu_0}{4\pi}\int \frac{\mathbf{j}(\mathbf{r}') \times (\mathbf{r}-\mathbf{r}')}{|\mathbf{r}-\mathbf{r}'|^3}\, d^3\mathbf{r}', \qquad (1)$$

$$J\,(r) d^3 r = I\,(r)\, dl \qquad (2)$$

Where:

I : is the vector current (*i.e.*, its direction and magnitude specify the direction and magnitude of the current) .

dl : is an element of length along the conductor.

μ_0 : Permeability of free space measured in Tesla .meter/ampere (T .m / A) $= 4\,\pi \times 10^{-7}\ T.m/A$

Equations (1) and (2) can be combined to give

$$\mathbf{B}(\mathbf{r}) = \frac{\mu_0}{4\pi}\int \frac{\mathbf{I}(\mathbf{r}') \times (\mathbf{r}-\mathbf{r}')}{|\mathbf{r}-\mathbf{r}'|^3}\, dl, \qquad (3)$$

If we consider an infinite straight conductor, directed along the z-axis, and carrying a current I as shown in figure (1) , then the magnetic field generated by the conductor at point ***P*** using the Biot-Savart law as follows:

water lines to which the electric system was grounded [16]

Negative health effects of EMF

The effect of EMF upon biological depends on both, the radiation's power and frequency. For lower frequencies of EMF up to those of visible light (i.e., radio, microwave, infrared), the damage done to cells and also to many ordinary materials under such conditions is determined mainly by heating effects, and thus by the radiation power. [17]. Electrical hypersensitivity (EHS) is a condition whereby the person suffers ill-health effects in the presence of electric or magnetic fields. Proximity to power lines, substations and cables is likely to make people suffering from this condition feel worse than the general population[18] .

Limit-compliance level of exposure to EMF according to ICNIRP Guidelines

Various organizations have set limits or published guidelines on exposure to EMFs to limit exposure to acceptably safe levels. Most have set the limits to prevent established effects at high fields principally induced currents but have not regarded the evidence for effects at lower fields such as cancer as strong enough to justify setting exposure limits. All exposures in homes and work places must comply with those limits to achieve the protection of workers and public from hazards[19]. The International Commission on Non Ionizing Radiation Protection (ICNIRP) published exposure limits in 1998. Table (1) lists the limit levels for electric and magnetic field prescribed by (ICNIRP) and the International BioInitiative Report (2007) which based on an analysis of 2,000 scientific studies[20].

10 m from the cable route, in increments of 1 meter at a height of 1m. Measurements are carried out by using the EMF- 827 tester with probe under assumption that the underground cables are in normal operation as shown in figure(2).

Results and discussion

Results of mathematical calculation and practical measurements for underground cable type A (11 kV) with (120 mm^2) and cable type B (11 kV) with (185 mm^2) are indicated in table (3) and the graph representation are indicated in figure (3).

Results of measurements for the two Cable types are indicated in table (4) and the graph representation are indicated in figure (4). To investigate the difference in levels of magnetic fields generated by 11 kV underground power cables and magnetic field generated by 11 kV over head power transmission line, we will measure them and make a comparison between these two levels .The max. field produced by a lattice pylon design when the ground clearance is the min. allowed (5.5 m) and the loads are the highest allowed not usually above 500 A in each circuit but there may be exceptions. Table (5) shows the measurements of magnetic field generated by11 kV over head power transmission line. The graph in figure (5) represent an illustration of comparison between one particular 11kv underground power cable and the equivalent 11kv overhead transmission line.

From all results obtained we can concluded that:

From the measurement results shown in figure (3) ,it is evident that the maximum magnetic field generated by the underground cable conductor with cross section of (120 mm^2) at a height of 1m above ground surface is exceed

Suppose that the perpendicular distance to the conductor is ρ so, it can be seen that:

$$\mathbf{I} \times (\mathbf{r} - \mathbf{r}') = I\rho\,\hat{\boldsymbol{\theta}}, \quad (4)$$

$$l = \rho \tan\phi, \quad (5)$$

$$dl = \frac{\rho}{\cos^2\phi}\, d\phi, \quad (6)$$

$$|\mathbf{r} - \mathbf{r}'| = \frac{\rho}{\cos\phi}. \quad (7)$$

Thus, according to Eq. (3), we have

$$B_\theta = \frac{\mu_0}{4\pi}\int_{-\pi/2}^{\pi/2} \frac{I\,\rho}{\rho^3\,(\cos\phi)^{-3}}\,\frac{\rho}{\cos^2\phi}\,d\phi$$

$$= \frac{\mu_0\, I}{4\pi\,\rho}\int_{-\pi/2}^{\pi/2}\cos\phi\, d\phi = \frac{\mu_0\, I}{4\pi\,\rho}\left[\sin\phi\right]_{-\pi/2}^{\pi/2}, \quad (8)$$

which gives the final result as :

$$B_\theta = \frac{\mu_0\, I}{2\pi\,\rho}. \quad (9)$$

In this work, the process of calculation of magnetic field g by (11kv) underground cables is conducted on two types of underground cables of different cross sections at one meter above the ground surface at a certain distances from the axis of the route of cable line. The calculation was performed for the case, in which flowing currents have a certain percentage of the maximum allowable current as follows:

a) Type A - 11%;

b) Type B - 10%

Table(2) shows the characteristics of the cable at which calculations of magnetic fields in their surroundings was conducted.

Practical measurements

As with the mathematical calculations, the measurements of magnetic fields are performed at the measuring points on both sides of the cable at distances up to underground power cables one of them is to place a cylindrical shell made of a ferromagnetic material. The principle for reducing the magnetic field outside the shield is that the ferromagnetic material absorbs the magnetic field generated by the buried power line and only a very small portion of the magnetic field survives outside the shield. As the shield is made of a high-conductivity ferromagnetic material, eddy currents are induced inside it and they generate a magnetic field opposed to the magnetic field generated by the power line. It results that the total magnetic field *H* inside the shield is reduced.

2-In order to minimize magnetic field levels, building wiring ideally needs to be enclosed in metal conduit or trucking, or screened mains cable should be used. Due to the low intensities of the magnetic fields generated by the underground power lines, it is very important to select a suitable material for the shield. In order to create an efficient magnetic shield, the materials suitable for building the shield should have a very high magnetic permeability value.

3-Concerned people must contact the local electricity company and ask them to measure the electromagnetic field levels in house, and to provide a plan showing all nearby underground electricity cables.

4-The measured EMF assessment should be included in every full building survey. The initial tests could be carried out in about 15 minutes. If high or suspicious readings are found, then a more thorough survey would be necessary. More detailed information can be obtained by data-logging EMF measurements over a period of several days.

5-We believe that it is inexcusable to continue to ignore the evidence that (3.21μT), at a distance (0 m) from axis of the cable and it decreases with increasing the distance from cable .

1. From Figure (4) , it is evident that the maximum magnetic field generated by the underground cable conductor with cross section of (185 mm^2) at a height of 1m above ground surface is exceed (3.91 μT), at a distance (0 m) from the axis of the cable and it decreases with increasing the distance from cable .
2. According to graph in figure (5), the ground-level magnetic fields from underground cables fall much more rapidly with distance than those from a corresponding overhead line, but can actually be higher at small distances from the cable.
3. According to the limits reference set by the international BioInitiative Report (2007) which based on an analysis of 2,000 scientific studies shown in table (1)) we can determine the safe and unsafe zones as follows:
4. At the ranges from 0 up to 8m from the centerline of the underground cable in the both sides of the cable rout ,the magnetic fields are more than the limit level B > 0.1μT), so they considered as unsafe zones for human health as shown in figure(6) .
5. At the ranges more than 8m from the centerline of the underground cable in the both sides of the cable rout, the magnetic fields are less than the limit level B < 0.1μT), so they considered as safe zones for human health as shown in figure (6).

Recommendation

Personal exposure to magnetic fields generated by underground distribution Power cables can be reduced by the following steps:

1-There are many ways to minimize the magnetic field levels generated by agenda to steer perception one way or the other.

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there is ill health effects associated with high voltage power lines, and almost certainly with other forms of electricity use.

6-We believe that every surveyor should carry a small, easy-to-use, electric and magnetic field tester in order to make a basic assessment of the ambient magnetic fields.

7-It is important that professional EMF surveyors are adequately trained - there is more to carrying out a complete assessment than simply walking about with a hand held EMF meter.

Conclusions

Magnetic field measurements are usually carry out to investigate the levels of EMF in order to minimize the effects of such fields on the public health and workers in workplaces . In this paper, the measurement of EMF generated by the 11kv underground power cables has been carried out. The resulting measurements for different cross section have been evaluated and compared and the safe and unsafe zones has been determined according to the limits reference set by the international Bio Initiative Report (2007) which based on an analysis of 2,000 scientific studies. Based on the results, it can be conclude that the maximum flux density of the EMF produced by underground power cables depends on the cross section of the cable and the current flow through it. These data are important for the categorization of underground distribution cables as well as individual sources of EMF. It can be very hard to say exactly what levels of EMF are safe, because safety in this arena is often a relative concept based on frequency, exposure time, and possibly individual sensitivity. Even then, studies are often considered inconclusive plus there is the potential for political and financial

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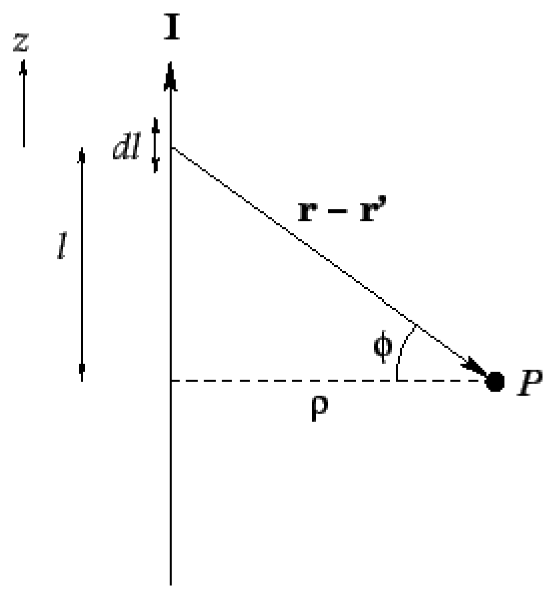


Figure(1): Infinite straight conductor, directed along the z-axis and carrying a current I

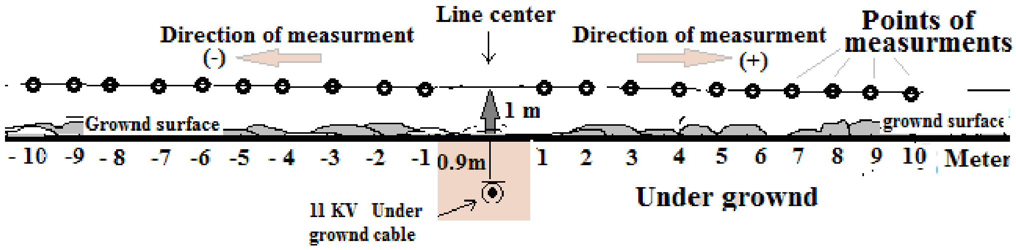


Figure (2) : Measuring points on both sides of cable at distances up to 10 m from the cable route, in increments of 1 meter from the route.

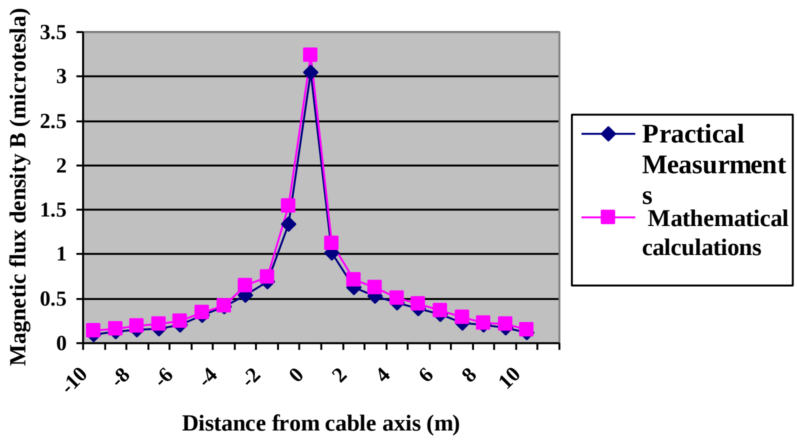


Figure (3): Graph representation of the practical measurements and mathematical calculations for (B) in case when using cable type A (11 kV),(120 mm^2) .

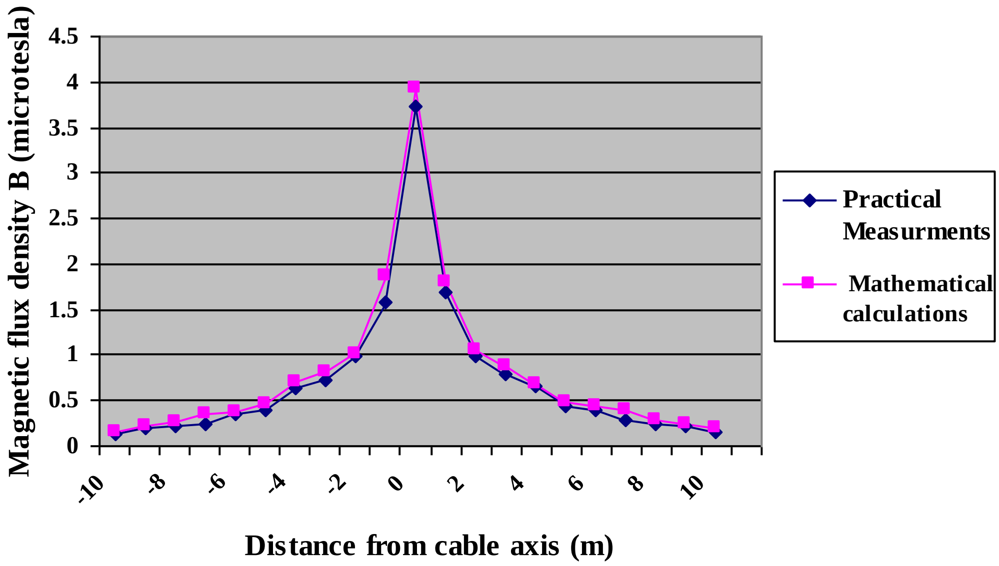
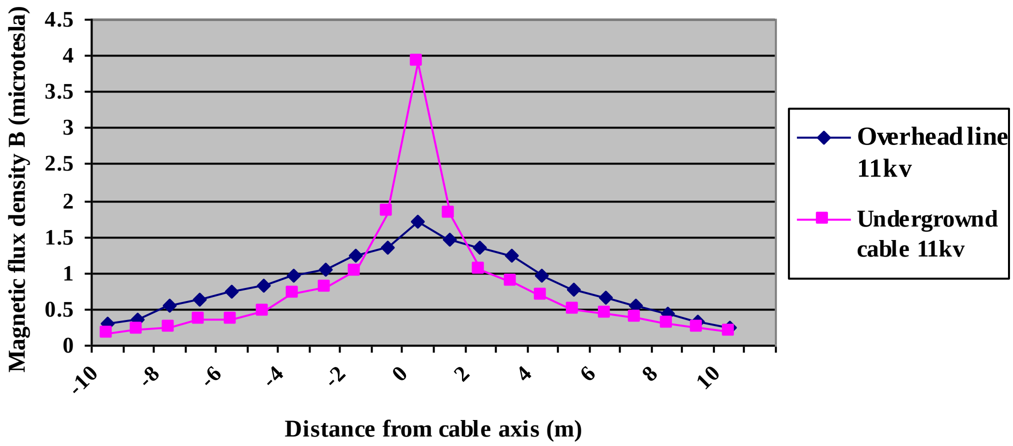


Figure.(4): Graph representation of the practical measurements and mathematical calculations for (B) in case when using cable type A (11 kV),(185 mm^2) .



Figure(5) :Graph of comparison between one particular underground cable and the equivalent overhead power transmission line.

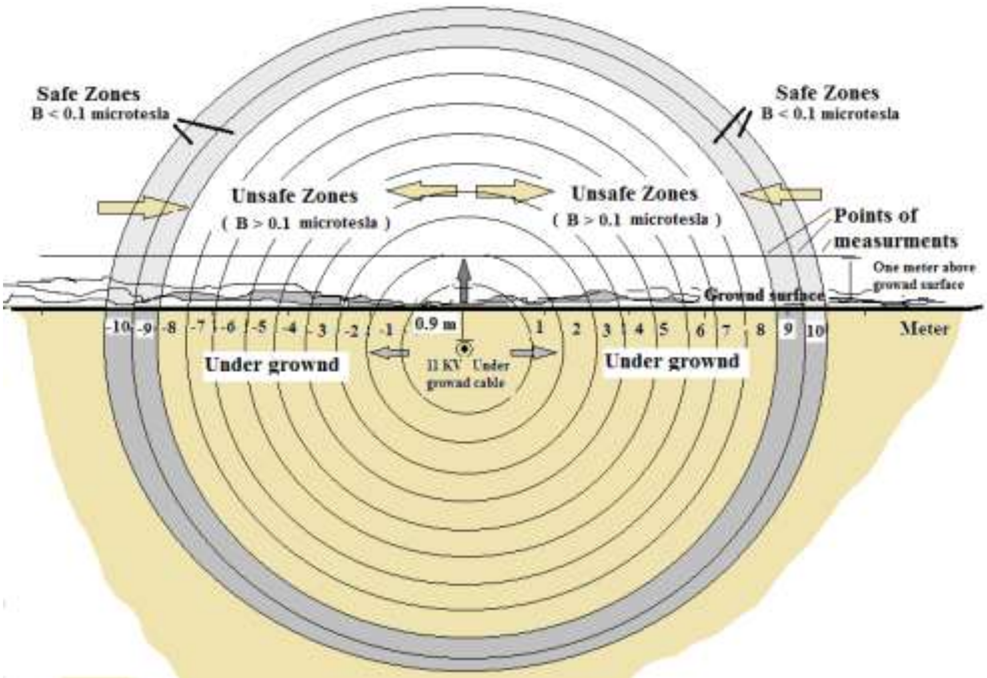


Figure.(6) : Safe and unsafe zones from the electromagnetic fields generated by the underground power cables.

Table (1): The limit levels for electric and magnetic field prescribed by the International BioInitiative Report (2007). [20]

Table	Frequency	Common Sources	Metric	Biological And Cancer Safety Limits	Heating And Shock Safety Limits (Icnirp)
A	30-300 Hz Extremely Low Frequency	power lines domestic, wiring, transformers	Magnetic Field	0.1µT	100 µT
B	0.3-300 kHz Low Frequency Voltage Transients	power lines ,domestic wiring, energy saving lights	Magnetic Field	0.025 µT	6.25 µT
			Electric Field	…	87 V/m
			Voltage transients	50 GS	…
C	300 kHz– 300 MHz Radio Frequency	radio tran-smitters, TV transmitters	Magnetic Field	…	0.092 µT
			Electric Field	0.194 V/m	28 V/m
D	0.3 – 300 GHz Microwave Frequency	mobile phones and masts, DECT cordless phones, WiFi, WiMAX	Elictric field (peak pulse)	0.02 V/mto0.6 V/m	41 V/Mto61 V/M

Table (2): Size data and current rating of the two types of underground cables.

Cable type	Cross section $(mm)^2$	Max. load current (A)	Depth of deposit(m)
A	120	282	0.9
B	185	361	0.9

Table (3). Maximum level of magnetic field practical measurements and mathematical calculations for cable type A (11 kV) ,(120 mm^2)obtained.

Distance from the cable axis at one meter above ground	practical measurements		mathematical calculations	
	B(μT)		B(μT)	
(m)	in one direction (-)	in the other direction (+)	in one direction(-)	in the other direction(+)
0	1.87	1.87	3. 21	3.21
1	0,78	0,89	0,83	0.87
2	0,67	0,69	0,71	0.75
3	0,59	0,62	0,61	0.65
4	0,51	0,54	0,53	0.57
5	0,42	0,44	0,44	0.49
6	0,36	0,39	0,40	0.43
7	0,26	0,29	0,29	0.34
8	0,21	0,24	0,23	0.27
9	0,19	0,23	0,22	0.26
10	0,12	0,14	0,15	0.18

Table (4). Maximum level of magnetic field practical measurements and mathematical calculations for Cable type A (11 KV) ,(185 mm^2)obtained.

Distance from the cable axis at one meter above ground	practical measurements		mathematical calculations	
	B (μT)		B (μT)	
(m)	in one direction(-)	in the other direction(+)	in one direction(-)	in the other direction(+)
0	3.74	3.74	3.91	3.91
1	1.58	1.69	1.68	1.81
2	0.98	0.99	1.02	1.05
3	0.64	0.71	0.78	0.87
4	0.69	0.75	0.74	0.87
5	0.40	0.43	0.46	0.49
6	0.35	0.39	0.37	0.43
7	0.25	0.29	0.35	0.39
8	0.22	0.24	0.26	0.29
9	0.19	0.23	0.22	0.24
10	0.14	0.16	0.17	0.19

Table (5) The measurements of magnetic field generated by the 11 kV overhead power transmission line.

Overhead transmission line 11 kV	magnetic field in (μT) at distance from center line						
	-30m	- 20m	-10m	under line at (0 m)	10 m	20 m	30 m
	0.007	0.027	0.131	3.94	0.134	0.030	0.008