THEORETICAL AND EXPERIMENTAL STUDY OF ELECTROMAGNETIC FIELDS AROUND HIGH POWER TRANSFORMER

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ABSTRACT

This study consists of three parts. Firstly theoretical study is explained. The electromagnetic field model of transformer is derived. Then using HI-3604 Power Frequency Field Strength Meter, the measurement of electromagnetic field around transformer is done. The electromagnetic fields that are measured and calculated are compared. Then the discussions about the result are evaluated and compared literature. Good agreement is found.

1. INTRODUCTION

Electromagnetic fields are divided into several categories according to their frequencies. Electric and magnetic fields from power lines are associated with the extremely low frequency (ELF) end of the electromagnetic spectrum.

Concerns about the possible health effects of magnetic fields seem to be greater than for the possible effects of electric fields at ELF range; this may relate to the fact that magnetic fields are not shielded by objects such as trees, walls, and buildings, while electric fields are. Some researches about this subject have done in recent years. According to these, the electromagnetic fields of electric power delivery are linked to a high incidence of cancer afflicting principally the blood, brain and breast. Cell growth mutation and disruption of hormonal and immune system controls are observed. Continuous exposure to electromagnetic fields above 0.08 A/m is probably hazardous and below **0.024 A/m** is probably safe. **[1]**

Also it was discovered that magnetic field strength of 1.2 A/m could produce noticeable distortions on the monitor of computers. Power substations and power networks of big buildings, factories carry high currents so not only the workers and individuals around but also the field sensitive devices inside these buildings can be affected by electromagnetic fields. The total electromagnetic field is composed of high current sources such as transformers, bus bars, distributors, and power cables. According to the International Commission on Non-Ionizing Radiation Protection (ICNIRP), the magnetic and electric fields are **79.58 A/m** and **5 kV/m** for public exposure. **[2]**

The magnetic fields from substation equipment like transformers, bus bars etc., are generally affected by variables like the magnitude of phase current, the configuration and height of conductor, and the distance etc. The magnetic fields decrease with the distance from the source and increasing the height of the current carrying conductors will reduce the magnetic fields near ground level. **[3]**

2. MAGNETIC FIELDS OF SUBSTATIONS

2.1 Magnetic Fields of Conductors

a) Field of Single Conductor

The Bio-Savart Law is used to calculate magnetic field intensity. **[4]** The magnetic fields from a single infinitely long straight conductor are circular emanating out from the center. The field intensity is

$$H = \frac{I}{2\pi d} \qquad (1)$$

where I is the peak current (A), and d is the distance between observation point and the origin (m).

b) Far Field of Bus Bars with four Conductors

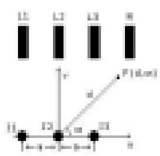

Fig 1. Bus bars with four Conductors

The line consisting of the conductors L1, L2, L3 and N (Fig 1) carries a symmetrical load such that the total amount of the three phase currents yields zero. Then the neutral conductor N is free of current and does not affect the magnetic field. The magnetic field intensity for infinite length is

$$H = I\sqrt{3}\,a \;\ldots \qquad (2)$$

where I is the peak current (A), a is the distance between two near conductors (m), and d is the distance between observation point and the origin (m). **[5]**

If the currents are unbalanced, the net current also affects the magnetic field.

If the conductor is semi-infinitely straight one, the field intensity is half of the infinitely conductor. (Fig 2)

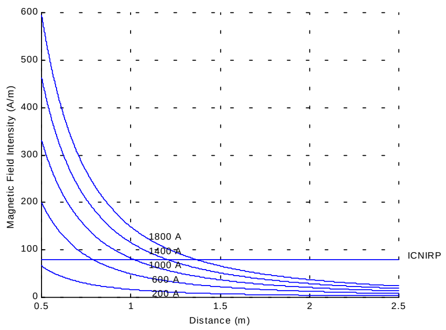

Fig 2. Magnetic Field vs distance of semi-infinity bus bars with four conductors for different currents ICNIRP is also shown. The distance between conductors is 0.6 m.

2.2 Magnetic Fields of Transformers

It is known that magnetic fields from high power substations constitute a health hazard. Substations serve many functions in controlling and transferring power on an electrical system. Substations may utilize transmission lines, distribution lines or both of them. In general the strongest magnetic fields around the outside of the substation comes from the power lines entering and leaving the station. While transformers inside the substation can produce high magnetic fields, the fields remain localized around the transformers. **[6]**

Step-up transformers are used at the power generating station to raise the voltage so the power can be economically delivered over transmission lines. The magnetic fields from these types of transformers are high but localized. Step-down transformers are used to reduce line voltages. Overhead (pole-mounted) transformers are used where distribution lines are overhead and surface (pad-mounted) transformers are used where distribution lines are underground. Frequently in urban situations, transformers can be located within buildings. If the transformer is what is referred to as a network transformer, which can supply power to an entire block, magnetic fields on the floor directly above the transformer can be as high as 56 A/m. Since magnetic fields remain localized around the transformer itself, a pole mounted transformer will have very little impact on ground level magnetic fields, which will be dominated by the overhead distribution lines coming in and going out of the transformer. Pad mounted transformers have magnetic fields similar in intensity to kitchen appliances. The magnetic fields near this type of transformer are elevated close to the surface of the transformer. A few feet away, the levels drop off to background. The magnetic fields are determined by both current and geometric information. The farther the source is the less the magnetic field. For magnetic fields generated by 3 phase AC currents, three spatial currents generally have different phase angle from each other, so that their vector sum rotates in a plane at the same frequency as the source currents. **[7]**

Calculation of Electromagnetic Field of Transformer

The distributing magnetic field of a three-field transformer is identical with the stray field of the transformer's iron core. In practice most equipment will behave as a collection of E and H dipoles. For our transformer model, we use ***magnetic dipoles***. According to the magnetic dipoles, the magnetic field expressions are like that **[8]**:

$$H_r = \frac{jk}{2\pi}\frac{AI\cos\theta}{r^2}\left(1+\frac{1}{jkr}\right)e^{-jkr}$$
$$H_\theta = \frac{-k^2}{4\pi}\frac{AI\sin\theta}{r}\left(1+\frac{1}{jkr}-\frac{1}{(kr)^2}\right)e^{-jkr} \qquad \mathrm{k} = \frac{2\pi}{\lambda}$$
$$H_\phi = 0$$

I is the current (A), A is the area of the loop (m^2), r is the distance (m), k is phase constant (rad/m). Since our wavelength is 6000 km, k is too small for ELF.

$$\lambda >> 0 \quad \mathrm{k} \cong 0 \quad \therefore\ e^{-jkd} \cong 1$$
$$H = \frac{jk}{2\pi}\frac{AI\cos\theta}{r^2}\left(1+\frac{1}{jkr}\right)a_r - \frac{k^2}{4\pi}\frac{AI\sin\theta}{r}\left(1+\frac{1}{jkr}-\frac{1}{(kr)^2}\right)a_\theta$$
$$kr << 1 \quad \mathrm{m = AI}$$
$$H = \frac{1}{4\pi}\frac{m}{r^3}(2\cos\theta\, a_r + \sin\theta\, a_\theta) \tag{3}$$
For the coaxial case (on the axis of the loop) $\theta = 0°$
$$\mathrm{H} = \frac{1}{2\pi}\frac{m}{r^3}a_r \quad \text{(A/m)}$$
For the coplanar case (in the plane of the loop) $\theta = 90°$
$$\mathrm{H} = \frac{1}{4\pi}\frac{m}{r^3}a_\theta \quad \text{(A/m)}$$

Eq.3 is used if the ratio of the radius of the loop (R) to distance is small. If this ratio is not small, we use the square root of (r^2+R^2) instead of r.

According to Maxwell equation the electric field is derived,

$$E = \frac{Zk^2}{4\pi}\frac{m\sin\theta}{r}\left(\left(1-\frac{j}{kr}\right)e^{-jkr}a_\phi\right) \qquad Z = \sqrt{(\mu/\varepsilon)}$$
$$\lambda >> 0 \quad \mathrm{k} \cong 0 \quad \therefore\ e^{-jkr} \cong 1$$
$$E = \frac{Zk^2}{4\pi}\frac{m\sin\theta}{r}\left(1-\frac{j}{kr}\right)a_\phi$$
$$kr << 1$$
$$E = \frac{Zk^2}{4\pi}\frac{m\sin\theta}{jkr^2}a_\phi \tag{4}$$
For $\theta = 90°$ (max value)
$$\mathrm{E} = 3.14 \cdot 10^{-5}\frac{m}{jr^2}a_\phi \ \text{(V/m)}$$

As a result of this, in the near field of the magnetic dipole, the magnetic field varies inversely with r^3 (Eq.3) and electric field that is unnecessary to measure varies with r^2. (Eq.4)

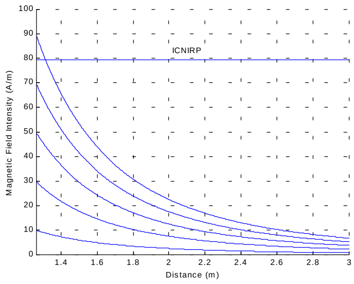

Fig 3. Magnetic Field Intensity vs distance of transformer different peak currents (400, 600, 1000, 1400, 1800 A (respectively to upper values)) (coplanar case) ICNIRP is also shown.

Three Phase Transformer

Data:

r=0.75 m (radius of solenoid)

h=2 m (height of transformer)

a=0.1 m (distance between solenoids)

d=distance between transformer and observer

According to the given data, the magnetic field intensity around the transformer at the height of 1 m is shown calculated by using magnetic dipole and shown in Fig 4. There are also three phase conductors on the low and high voltage side of the transformer. These magnetic fields are dominant around their nearer region and are calculated (Eq. 2). In Fig 4, only the front and the right side of the transformer are shown because the other sides are the symmetries of both. The fields are changing while walking on the line. At the end of each line, fields are decreasing because of the increasing the distance to the source as well.

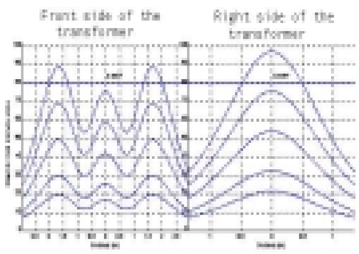

Fig 4. Magnetic field of three phase transformer for different currents (400, 600, 1000, 1400, 1800 A (respectively to upper values)) at d=0.5 m

Also if we want to calculate the top side of the transformer, the magnetic field is twice of the back side's fields because of the coaxial case.

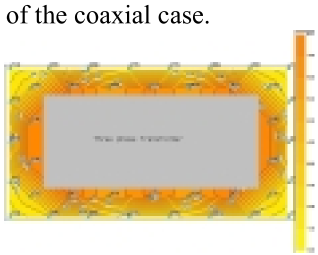

Fig 5. Contour plots of magnetic field for three phase transformer

Although most transformers are generally shielded, the electromagnetic field shows its effect to public area situated in cities. And the workers in most factories, TEDAŞ are living with this effect.

3. MEASUREMENT PROCESS

The measurement process is done by using HI-3604 equipment of Holaday Industries. The HI-3604 Power Frequency Strength Measurement System is designed to assist in the evaluation of electric and magnetic fields that are associated with 50 Hz electric power transmission, distribution lines along, electrically operated equipments and appliances. **[9]**

While studying contour plots of magnetic field, a pair of rectangular axes has been chosen. An x-axis and y-axis can be selected according to the transformer. The magnetic field intensity in A/m for the current conditions were measured at points expressed in terms of their x and y coordinates. Then the H values between consecutive points are interpolated in order to find the x and y coordinates of all points with the same value of H. These points are then plotted, points with the same H value being joined by the equal flux density contour lines. (Fig 5) The electric and magnetic fields should be measured at a height of 1 m above the ground level.

4. RESULTS AND DISCUSSIONS

Measurement of Magnetic Field around Transformer at TEDAŞ SAKARYA

Measurements have been done in the afternoon on 25 May 2001.

1- 380 kV \ 154 kV Transformer:

According to 380 kV \ 154 kV Transformer the measurement results is between 0.82 and 3.82 A/m for d=2.5m. (while measuring magnetic field, the current 150 A passes from low voltage side and 70 for the other side at that moment) Its maximum power is 150 MW which means that its maximum current is 562 A.(150M/154k/sqrt(3))

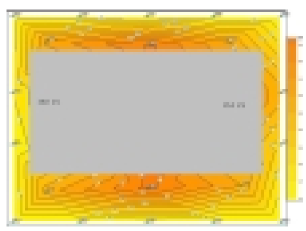

Fig 6. Contour plots of magnetic field for 380kV/154kV Tr.

According to the measurement result the maximum magnetic field is found at the low voltage side and the mid-region of the transformer. So the measurement process is not likely the same on the right and left side. Also the measured magnetic fields are higher than the theoretical ones because of the fields' contribution of the other equipments.

2- 154 kV \ 34.5 kV Transformer:

According to 154 kV \ 34.5 kV Transformer the measurement results is between 0.83 and 3.11 A/m for 2.5 m. (while measuring magnetic field, the current 350 A passes from low voltage side and 170 for the other side at that moment) Its maximum power is 100 MW which means that its maximum current is 1650 A.

According to the measurement result, the maximum magnetic field is found at the low voltage side of the transformer again due to the conductors' effect. Also the measured magnetic fields are higher than the theoretical ones because of the fields of other equipment.

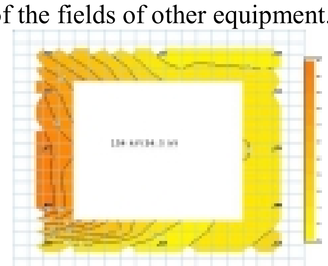

Fig 7. Contour plots of magnetic field for 154kV/34.5kV Tr.

While we study the contour plot of transformers (Fig 6), 380kV\115kV transformer is nearly same as the theoretical one. Results of measurement indicated that the highest magnetic field was present in the low voltage side of transformer. (Fig 6-7) Also the field of conductors affects the measured magnetic field.

While doing the measurement process, the magnetic field didn't exceed the 79.58 A/m. If the maximum current is applied to the transformer the first one can't exceed 79.58 A/m, but the second can exceed. The measurement process is done 2.5 m away from the source. If the distance is decreased, the magnetic field increases more rapidly. (Increases with r^3). And if we are above the transformer the fields are 2 times of the measured.

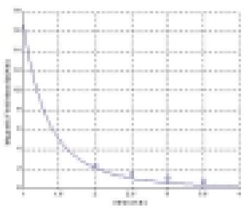

Fig 8 Comparison of measured (plotted) and theoretical (curved) values of 154kV/34.5kV Tr. against distance

The above measured values are nearly same as the theoretical ones. But the measured magnetic field is above the curve. The reason can be the magnetic field of conductors or other substances.

The conductors on the low voltage side of the transformer affect the measurement process. On the high and low voltage side we couldn't find the wanted values. But on the other sides of the transformer, we found the nearly same value.

While calculating the theoretical values, some mistakes can be done because of the distance between the solenoids, the position of transformer. Also if we decrease the distance in our model, mistakes can be made due to not use the radius of solenoid in our calculation.

Also measurement mistakes while measuring the distance and magnetic field shouldn't be forgotten.

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