APPLYING A SIMPLE APPROACH FOR EVALUATING THE MAGNETIC FIELDS PRODUCED BY POWER LINES

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ABSTRACT
The paper applies a new method for evaluating magnetic fields produced far from power lines. Simple formulae are used for calculating the magnitudes of the resultant, semi-major and semi-minor axes that characterize the magnetic fields produced by various power-line configurations.

We analyze the first few terms of the power series that expresses the magnetic field produced by an assembly of parallel line currents, such as those used to approximate the conductors of electric-power transmission and distribution lines. The properties of the first few terms of this series will be described. Some assumptions have been taken into consideration.

Field measurements were carried out for magnetic flux densities produced at large distances by three-phase power lines. The results were compared with the calculated values.

Several methods for reducing the magnetic field generated by power lines are addressed.

INTRODUCTION
Since about 1970, public and scientific interest in the possible biological effects of power-frequency Electric and Magnetic Fields (EMF) has continued to increase.

These fields are produced by all electrical equipment and devices, including household appliances, distribution and power lines. Various effects of EMF have been reported under laboratory conditions. Several epidemiological studies also suggest an association between magnetic and/or electric fields and cancer in children living near high current power lines and in men working around electric power facilities and equipment. To date, however, no causal link between EMF and adverse health effects, including effects on fertility, has been established. Utilities have developed and implemented integrated action plans in response to concerns about health impacts from the electric utility facilities EMFs. The justification for these actions is the desire to appropriately cautious in the face on uncertainty. EMF has not been established to have either worker or community health impacts, nor is there sufficient information available to set public health standards. However, utilities perform researches to get needed information to answer the remaining questions, to ensure the meaningful participation of people interested in the decision making process and to take appropriate actions in preparation for an uncertain future. While these actions may or may not have any actual public health benefits, they are justified as long as the costs are reasonable, they do not adversely affect electric system reliability, safety or cost impacts, and do not impact the appropriate allocation of individual or social public health resources.

GENERAL ANALYSIS
Exposure of humans to the magnetic fields produced by electric power transmission and distribution lines usually occurs at “far” distances, that is, at distances large in comparison to the spacings between the line's phase conductors.

Texts in electromagnetic theory show how the magnetic field produced by a current distribution localized in all three spatial dimensions can be expressed as a power series whose successive terms are proportional to $1/R$, $1/R^2$, $1/R^3$, ..., where R is the distance between the source and the point where the field is to be determined (i.e., the field point).

The advantage of this approach is that the lowest –order non-zero term in the series becomes dominant as R becomes large.

In this paper we analyze the first few terms of the power series that expresses the magnetic field produced by an assembly of parallel line currents, such as those used to approximate the conductors of electric power transmission and distribution lines. The properties of the first few terms of this series will be described. It will be shown that the magnetic fields produced by conventional power lines have remarkable similarities. Simple formulae will be applied for magnetic fields produced by line configurations.

SERIES EXPANSION
Consider an assembly of N long, straight conductors parallel to the Z axis (Fig. 1). Except near their ends, the fields produced by these conductors will depend only on the transverse coordinates X and Y. Therefore, the analysis may be restricted to the plane Z=0. Let the position of the kth conductor be the vector $r_k$ directed from the origin of coordinates to the point where the conductor intersects the XY plane (Fig. 1). From the Biot - Savart law, the magnetic flux density, B, in units of tesla (T) produced by the assembly of conductors is:
We now restrict our attention to field points such that \( R > d \) (i.e., the line's phase spacing), where \( d \) is the distance from the center of the assembly of conductors to the field point, and the terms not shown are proportional to higher powers of \( \frac{1}{R} \).

Inserting this expression in equation (2) and collecting together terms proportional to \( \frac{1}{R} \), \( \frac{1}{R^2} \), etc., we find that

\[
B(R) = B_1(R) + B_2(R) + B_3(R) + B_4(R) + \ldots \]

Where:

\[
B_1(R) = \frac{\mu_0}{2\pi R} \sum_{k=1}^{N} I_k \hat{Z} \times \hat{R} \]

\[
B_2(R) = \frac{\mu_0}{2\pi R} \left[ \sum_{k=1}^{N} I_k \frac{d_k}{R} \hat{Z} \times \hat{R} \right] \]

\[
B_3(R) = \frac{\mu_0}{2\pi R} \left[ \sum_{k=1}^{N} I_k \frac{d_k^2}{R^2} \hat{Z} \times \hat{R} \right]
\]

\[
B_4(R) = \frac{\mu_0}{2\pi R} \left[ \sum_{k=1}^{N} I_k \frac{d_k^3}{R^3} \hat{Z} \times \hat{R} \right]
\]

**First-order Term**

The first order term given by equation (4) can be simplified by defining the net current, \( I_n \), to be the phasor sum of all the conductor currents, in this case:

\[
B_1(R) = \frac{\mu_0 I_n}{2\pi R} \hat{Z} \times \hat{R}
\]

The field \( B_1 \) is always perpendicular to \( \hat{R} \), so a rotation of \( \hat{R} \) through an angle \( \theta \) will result in a rotation of \( B_1 \) in the same direction. Because the vector \( \hat{Z} \times \hat{R} \) that appears in equation (8) is of unit length, the rms resultant value of \( B_1 \) is:

\[
(B_1)_{\text{rms}} = \sqrt{B_x^2 + B_y^2 + B_z^2} = \frac{\mu_0 |I_n|}{2\pi R}
\]

Where:

\( |I_n| \): the rms magnitude of the net current.

**Second-order Term**

The second order term given by equation (5) may be rewritten:

\[
B_2 = \frac{\mu_0}{2\pi R^2} \left[ 2(\hat{R} \cdot M_2) \hat{Z} \times \hat{R} - \hat{Z} \times M_2 \right]
\]
With the second-order moment vector, $M_2$, defined to be:

$$M_2 = \sum_{k=1}^{N} I_k d_k$$

An important property of $M_2$ is that its direction and magnitude are independent of the exact location, $r_o$, selected to be the center of the system of conductors if the net current of the system is zero. Thus, any convenient origin can be used for the calculation of $M_2$.

The real and imaginary parts of a vector field must be separately analyzed to obtain a complete description of the field's behaviour.

The resultant magnitude of the second-order flux density is:

$$(B_2)_{\text{rms}} = \sqrt{B_2 \cdot B_2^*} = \frac{\mu_0}{2\pi R^2} \sqrt{M_2 \cdot M_2^*}$$ (11)

$(B_2)_{\text{rms}}$ depends on the distance, but not the direction, between the source and field points.

The semimajor and semiminor values of the second – order magnetic field and moment vector are simply related by the equations

$$(B_2)^{\text{maj}} = \frac{\mu_0}{2\pi R^2} (M_2)^{\text{maj}}, (B_2)^{\text{min}} = \frac{\mu_0}{2\pi R^2} (M_2)^{\text{min}}$$ (12)

Following procedures similar to those used in analyzing the second – order field, equations for the rms resultant, semimajor and semiminor values of the third and fourth – order magnetic fields can be obtained.

**SELECTED APPLICATIONS**

Table 1 gives simplified formulae for calculating magnetic flux densities produced at large distances by two configurations of single circuit – three phase electric power lines,

- Lines are assumed to be carrying phase currents with equal magnitudes, I,
- S is the distance between the conductors
- $B_{\text{rms}}$ is the rms resultant flux density

**Table 1 – The simplified formulae for calculating magnetic field**

<table>
<thead>
<tr>
<th>Line configuration</th>
<th>Magnetic flux density (mG)</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Line configuration" /></td>
<td>$B_{\text{rms}} = B_{\text{maj}} = \frac{\mu_0}{2\pi R^2} \sqrt{3SI}$</td>
</tr>
<tr>
<td><img src="image" alt="Line configuration" /></td>
<td>$B_{\text{rms}} = B_{\text{maj}} = \frac{\mu_0}{4\pi R^2} \sqrt{6SI}$</td>
</tr>
</tbody>
</table>

**MAGNETIC FIELD MEASUREMENTS**

**Procedure for Measuring the Magnetic Field Near Power Lines**

According to IEEE Std 644 – 1994, the magnetic field under power lines should be measured at a height of 1 meter above the ground level. Field meters with three-axis probes may be used to measure the resultant magnetic field.

The longitudinal profile of the field strength should be measured where the field is greatest at midspan or other points of interest, as determined from the lateral profile, parallel with the line and 1 meter above the ground level.

The lateral profile of the magnetic field strength at points of interest along a span should be measured at selected intervals in a direction normal to the line at 1 meter above the ground level. At least five equally spaced measurements should be performed while under the conductors.

**Results**

Magnetic field measurements were conducted under various Medium Voltage (MV) distribution lines (20kV and 11kV).

The majority of the MV distribution towers in Alexandria city carry the phase conductors of one line arranged in trefoil formation. Magnetic field measurements were carried out using PMM8053B logger with EHP-50C probe meter.

The results were compared with the calculated values using formulae in table 1.

Figures 2, 3 show the measured and calculated magnetic fields for longitudinal profiles of the lines. Figures 4, 5 show the measured and calculated magnetic fields for the lateral profiles of the lines.
Both measurements and calculations are carried out for one segment along each line. For the longitudinal profile, calculations took into account the sag of the conductors. The results show that errors between the measured and the calculated values are less than ±10%.

METHODS FOR REDUCING THE MAGNETIC FIELD

There are two main approaches for magnetic field mitigation:
- To reduce the field at source.
- To shield the field with magnetic or conductive materials.

Methods that reduce the field at the source generally take advantage of the cancellation effect of the fields generated by current circulating in a set of parallel conductors.

There are several methods for reducing the magnetic field generated by overhead and underground distribution networks by modifying some parameters:
- For an overhead line, it is possible to reduce the magnetic field by splitting the phases.
- If the currents in the three phases are not identical, the magnetic coupling between the line and the neutral conductor forces a certain percent of the unbalance current to return to the substation by the neutral conductor. This significantly increases the magnetic field of the line comparatively to a balanced line.
- Experiments proved that when an electric network comprises two or more three phase circuits, the optimization of phase configuration reduces the magnetic field by 4 to 7 times.

It is possible to shield a magnetic field by ferromagnetic or conductive materials:
- A magnetic or conductive material shields the field by deviating and concentrating it.
- For conductive material, the attenuation of the magnetic field results from the currents induced in the material by the magnetic field that partly cancels the incident field.

CONCLUSIONS

The paper applied a method for evaluating magnetic fields produced far from power lines, and presented simple equations for calculating the magnitudes of the resultant, semimajor and semiminor axes that characterise the magnetic fields produced by conventional single-circuit three phase configurations.

Magnetic field measurements were conducted under various Medium Voltage distribution lines. The results were compared with the calculated values and errors were found to be small.

Several approaches for reducing the magnetic field generated by distribution networks are addressed.

REFERENCES


