ASSESSMENT OF MAGNETIC FIELD MITIGATION METHODS FOR DISTRIBUTION NETWORKS

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ABSTRACT

Several methods for reducing the magnetic field generated by overhead and underground distribution networks are evaluated. These methods are: 1) optimization of the phase configuration for two or more 3-phase circuits, 2) rebalancing the currents of an unbalanced 3-phase circuit, 3) reduction of the conductor-to-conductor distance, 4) use of an overhead split-phase line and 5) shielding by conductive materials.
The first two methods can be implemented at very low cost. Methods 3, 4 and 5 involve additional costs comparatively to usual practices and can be implemented on a case-to-case basis to solve specific problems. The assessment of mitigation methods has been done by calculating the magnetic field in two dimensions (2D). Contrary to the conventional magnetic field profile at 1 m above the ground, 2D calculations allow the assessment of the propagation of the field in the space around a distribution network and eventually in buildings close to this network.

MAGNETIC FIELD GENERATED BY SIMPLE CONFIGURATIONS

The magnetic field generated by a single conductor (for example a ground conductor) is tangent to a circle centered on the conductor and decreases as the inverse of the distance (Figure 1).

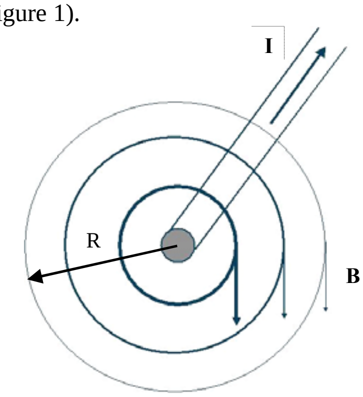

Figure 1: Magnetic field generated by a single conductor

The magnetic field can be calculated by a very simple equation:

$$B = \frac{0.2\ I}{R} \qquad (1)$$

where
I is the current carried by the conductor (A)
R is the distance perpendicular to the conductor (m)
B is the magnetic field in microtesla (µT)

With two parallel conductors carrying identical currents that circulate in opposite directions, the magnetic field generated by one conductor is partly cancelled by the field generated by the other one (Figure 2). The field generated by the right conductor is oriented in the upper direction while the one from the left conductor is in the opposite direction but its intensity is lower. The vectorial sum of these two fields results in a magnetic field B much lower than the field generated by a single conductor carrying the same current. Moreover the field decreases more rapidly with the distance (as $1/R^2$).

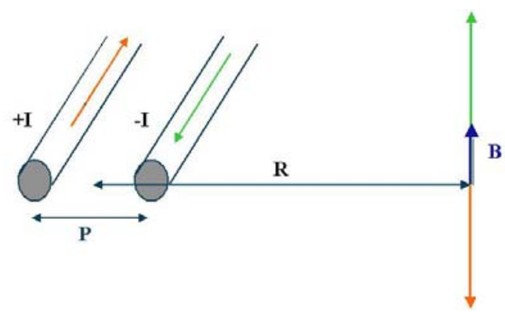

Figure 2: Magnetic field generated by two parallel conductors carrying identical currents but in opposite directions

The field generated by two parallel conductors (for instance a single phase circuit) can be calculated approximately by the following equation:

$$B \approx \frac{0.2\ I\ P}{R^2} \quad \text{for } R>>P \qquad (2)$$

where P is the distance between conductors [1].

For a 3-phase circuit (for instance a horizontal overhead distribution line), there is as well a cancellation effect and the field decreases also as the square of the distance according to the equation:

$$B \approx \frac{0.346\ I\ P}{R^2} \quad \text{for } R>>P \qquad (3)$$

It is important to note that the cancellation effect is maximum when the current is identical in each conductor.

If the conductors are positioned in a delta configuration (equilateral triangle) the field is approximately 30% lower comparatively to a horizontal or vertical configuration. For a double circuit line, the geometry of the line and the phase configuration play an important role in the intensity of the field generated. If the six conductors are uniformly distributed on a circle and with the optimum configuration of the phases, the field decreases extremely rapidly, that is as $1/R^3$.

In summary, some parameters can be modified in order to reduce a magnetic field: 1) distance between conductors, 2) currents, 3) phase configuration and 4) geometry. We will see how these parameters affect the magnetic field generated by distribution networks.

REDUCTION OF THE CONDUCTOR-TO-CONDUCTOR DISTANCE

As shown previously, the magnetic field generated by a 3-phase line is directly proportional to the distance between conductors. For an overhead line, the minimal distance between conductors is dictated by electrical insulation considerations and by live working procedures. It is possible to reduce this distance by using insulated conductors. There are two options: an overhead line with insulated conductors supported by a compact triangular support or an underground line. Figure 3 shows that the filed generated by an underground line extends only few meters comparatively to an overhead line (conductor-to-conductor distance: 1,12 m).

The magnetic field 2D representation allows the assessment of the propagation of the field in the space around the line and eventually in buildings close to this line (it is assumed that the structure of a building does not attenuate significantly the magnetic field).

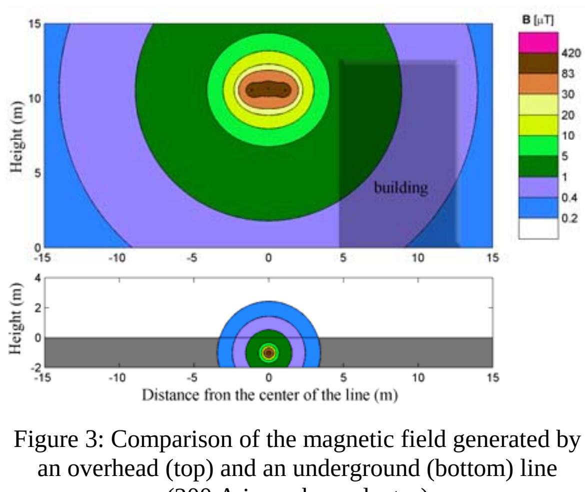

Figure 3: Comparison of the magnetic field generated by an overhead (top) and an underground (bottom) line (200 A in each conductor)

EFFECT OF UNBALANCED CURRENTS

North American distribution networks use a Y configuration with multiple grounds along the line. With this type of network, the currents in the three phases are generally not identical. The magnetic coupling between the line and the neutral conductor forces approximately 50% of the unbalance current to return to the substation by the neutral conductor [2]. Figure 4 shows that an unbalanced current of 60 A (30 % of the line current) significantly increase the magnetic field on one side of the line comparatively to a balanced line (Figure 3).

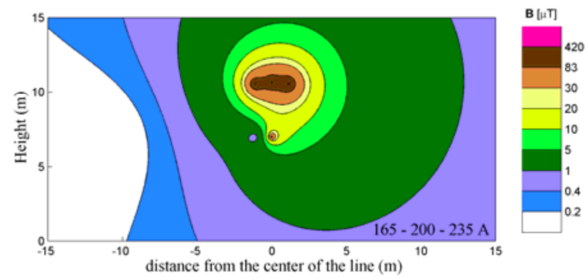

Figure 4: Field distortion caused by unbalanced currents

PHASES CONFIGURATION OPTIMIZATION

When an electric network comprises two or more three-phase circuits, the optimization of phase configuration is a low cost and very effective way to reduce the magnetic field. Figure 5 shows a 2D representation of the field produced by a double circuit line with two different phase configurations: the reference configuration ABC-ABC and the optimum configuration ABC-CBA. Directly under the line, the magnetic field is reduced by 4,1 times and by 6,2 times at 10 m from the center of the line (at 1 m above the ground).

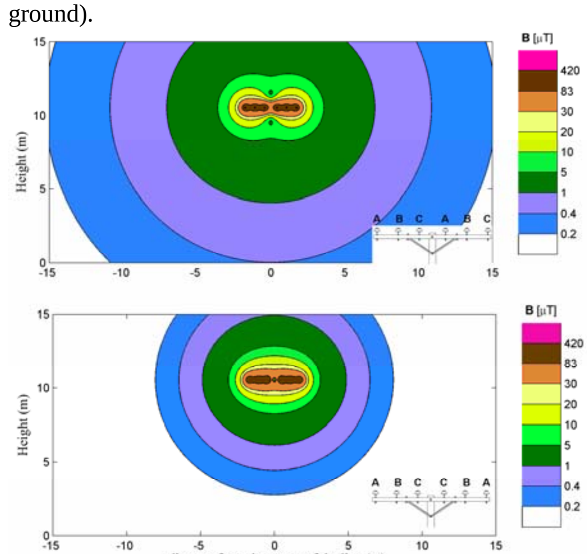

Figure 5: Magnetic field reduction by optimization of the phase configuration (100 A in each conductor)

SPLIT-PHASE LINE

We have seen that the optimization of the phase configuration is a very efficient method to reduce magnetic field. However this method is applicable only with two or more three-phase circuits. It is possible to create the equivalent of a double circuit line by adding two conductors on a three-phase line. These two conductors are connected in parallel to phase A and C respectively in order to split the current of these phases and to get the following sequence: A/2 - C/2 – B - C/2 - A/2. The magnetic field produced by a split phase line is much lower (9,1 times under the line and 13,4 times at 10 m) than the corresponding 3-phase line (Figure 6) and slightly lower than the field generated by a double circuit line (Figure 5).

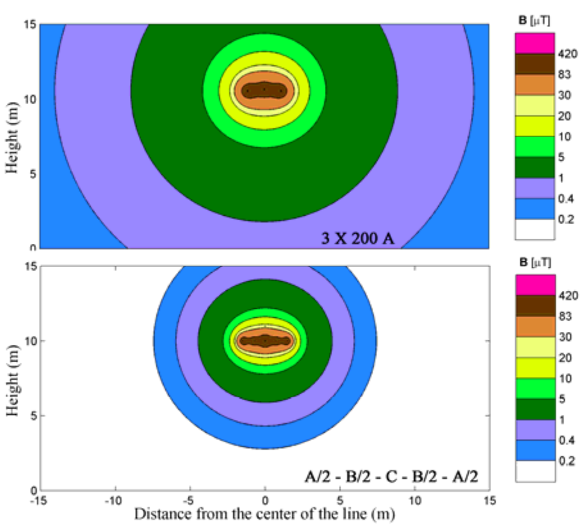

Figure 6: Reduction of the magnetic field by splitting phase A and B

SINGLE-PHASE VS 3-PHASE LINE

A single-phase line generates a relatively high field for two reasons: the distance between phase and neutral conductors is significant (2 to 3m) and the neutral conductor generally carries only approximately 50% of the line current [2], limiting the cancellation effect of the return current (see Figure 2). Reducing the resistance of the neutral conductor will not increase significantly the percentage of the return current in the neutral conductor. One option would be to use, when it is possible, a 3-phase line instead of a single-phase line. For the same power, a 3-phase line generates a much lower field than a single-phase line (Figure 7). Directly under the single-phase line there is an area where the field is very low due to the cancellation effect but at 10 m from the center of the line, the magnetic field is 9,5 times higher than the field produced by a 3-phase line carrying the same power.

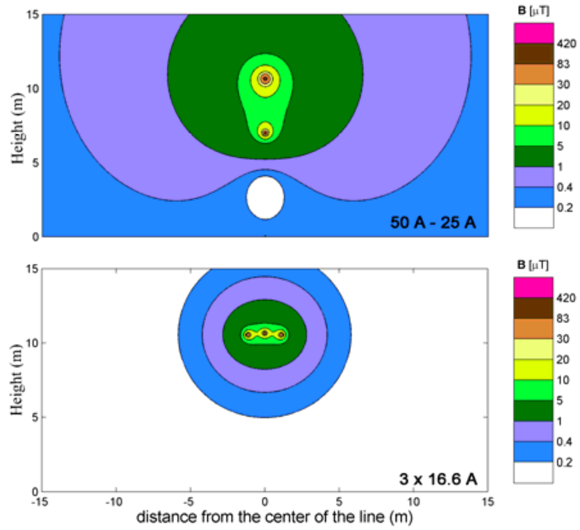

Figure 7: Comparison of the field generated by a single-phase line (top) and a 3-phase line (bottom) carrying the same power

SHIELDING WITH ALUMINIUM PLATES

It is possible to shield a magnetic field by ferromagnetic or conductive materials [3]. These two types of materials shield magnetic fields by different mechanisms. A magnetic material shields the field by deviating and concentrating it. In other words, the magnetic material constitutes a preferential pathway for the magnetic field. For conductive material, the attenuation of the magnetic field results from the currents induced in the material by the magnetic field. These induced currents generate a magnetic field that partly cancels the incident field.

We have assessed theoretically and experimentally the efficiency of an aluminium shield for underground cables. The experimental setup comprised a inverted U-shaped box (0,6 m x 0,6 m x 2,4 m) made with 10 mm aluminium plates welded together. A rectangular loop fed by a current transformer was installed inside the box. This loop carried a current of 500 A (Figure 8).

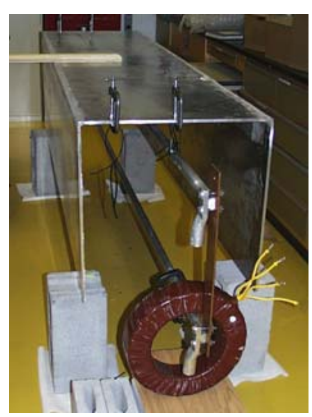

Figure 8: Aluminium shield experimental setup

Figure 9 shows that the magnetic field directly over the aluminium box is strongly reduced but the efficiency of the shield is less at 200 cm. This figure shows also that experimental results agree quite well with theoretical calculations.

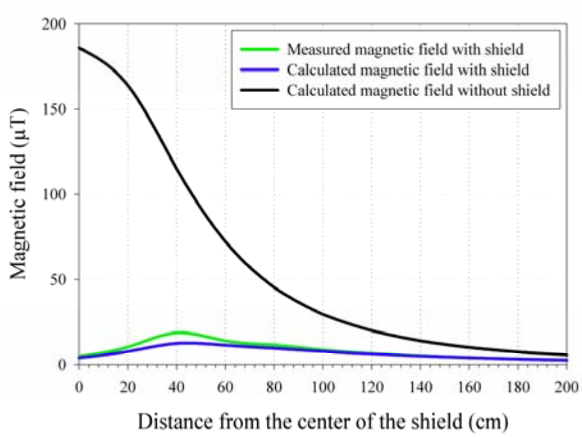

Figure 9: U-shaped aluminium shield efficiency

CONCLUSIONS

There are two main approaches for magnetic field mitigation: to reduce the field at source or to shield the field with magnetic or conductive materials (Table 1). Methods that reduce the field at the source generally take advantage of the cancellation effect of the fields generated by currents circulating in a set of parallel conductors. The optimization of the phase configuration is a very effective and low cost solution. Using a split-phase line is also a very effective solution but it involves additional costs and substantial modifications to conventional 3-phases overhead lines. Installing an underground line instead of an overhead one will reduce significantly the magnetic field but at a 5 to 10 times higher cost. Shielding a magnetic field with aluminum plates is a complex and costly solution that can be implemented only on underground network.

Acknowledgments

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[2] Y. Rajotte et al., 1995, “Impedance of multigrounded neutrals on rural distribution systems”, *IEEE Transactions on Power Delivery*, Vol. 10, No 3

[3] J. Hoeffelman, 2003, “Shielding of underground power cables, from theory to practical implementation”, *Conference* CIRED 2003.

<table>
<tr><th rowspan="2">Mitigation methods</th><th colspan="3">Overhead lines</th><th colspan="2">Underground network</th></tr>
<tr><th>Single-phase</th><th>3-phase</th><th>Double circuit</th><th>Cables</th><th>Substation</th></tr>
<tr><td rowspan="2">Reduction of conductor to conductor distance</td><td>Neutral closer to the line</td><td>OH Insulated conductors</td><td>OH Insulated conductors</td><td rowspan="2">N. A.</td><td rowspan="2">Yes</td></tr>
<tr><td colspan="3">Underground line</td></tr>
<tr><td>Phases configuration optimisation</td><td>N. A.</td><td>N. A.</td><td>Yes</td><td>N. A.</td><td>Yes</td></tr>
<tr><td>Split-phase line</td><td>3-phase line</td><td>Yes</td><td>N. A.</td><td>N. A.</td><td>N. A.</td></tr>
<tr><td>Rebalancing currents</td><td>N. A.</td><td>Yes</td><td>Yes</td><td>Limited efficiency</td><td>Yes</td></tr>
<tr><td>Shielding</td><td>N. A.</td><td>N. A.</td><td>N. A.</td><td>Steel pipes or Al plates</td><td>Aluminium plates</td></tr>
</table>

Table 1: Summary of magnetic field mitigation methods

Note: methods in **bold** can be implemented at very low cost.