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Improving Magnetic Field Mitigation Under Power Lines Using a Single Passive Loop with External Capacitance †

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Abstract

This paper presents the applications of a single passive loop for the mitigation of industrial frequency magnetic fields in the vicinity of medium and high voltage overhead power lines. Based on the fundamental theoretical aspects, the numerical results of the attenuation effect are simulated for different loop geometries installed at different heights under the conductors. By adding an external capacitor in the circuit, the influence of the passive element will be analyzed and the efficiency it brings in the magnetic field mitigation will be interpreted. The results highlight the fact that adding an external capacitor in passive loops can effectively reduce the nearby magnetic fields under the overhead power lines.

Keywords: magnetic fields; power lines; passive loops; external capacitor; medium and high voltage power lines; attenuation

1. Introduction

Exposure to electromagnetic fields has become a growing concern, particularly due to public perception of the potential risks. Although there is no clear evidence of associations between exposure and disease occurrence, this has intensified research in both the medical and technical fields. Power frequency remains the most relevant area, as electrical power equipment is widespread and generates significant magnetic fields [1–12].

Referring to the previous study, which analyzed the implementation of a single passive loop and two passive loops and compared their efficiency in reducing the magnetic field, the present work extends the investigation by introducing an external capacitor [1,4,5,13]. The impact of this addition on the magnetic field mitigation is evaluated further. In the continuation of the work, the obtaining of a single loop for the medium voltage line (conductors in the line) and the 110 kV line will be presented, the addition of a capacitor for the case of one loop as well as the comparison of the results.

In order to ensure a coherent and well-grounded continuity with the scientific approach initiated in the previous study, this work aims to further develop, clarify, and expand the earlier analysis [13].

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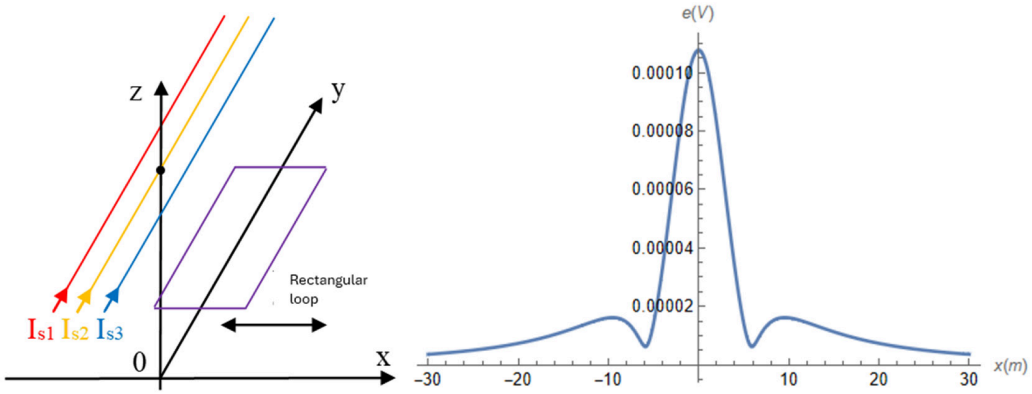
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2. Theoretical Backgrounds

We further consider the representation in Figure 1a, where, in the vicinity of a three-phase electric line carrying a current, there is a rectangular loop that is assumed to be able to be moved horizontally in the 0x direction [13].



(**a**) (**b**)

Figure 1. (**a**) Rectangular loop in the vicinity of a three-phase power line; (**b**) Variation of the induced EMF in the rectangular loop with its position on the 0x axis in the case of a three-phase power line.

The variation of the induced EMF in the rectangular loop when moving horizontally under the three-phase line conductors is shown in Figure 1b. This figure illustrates a very important thing, namely that in the case of a three-phase electric line with the conductors in line, the maximum value of the induced EMF in the loop is obtained when it is positioned exactly under the line conductors, symmetrically with respect to the line. This fact is very important, since from a practical constructive point of view, the rectangular loop is the easiest to mount symmetrically, under the line conductors.

Following the equivalent circuit in Figure 2, which is in fact the simple R-L-C type circuit, the idea naturally arises that the use of external capacitances connected in series in the circuit would improve the value of the current induced in the loop in the sense of increasing its value through the series resonance phenomenon and implicitly the value of the magnetic field induced as the reaction. The equivalent impedances that include the external capacitances are, respectively, those in relation (1) customized for each circuit in part [13–15].

$$Z = R + j\omega L + \frac{1}{j\omega C_{ext}} = R + j\left(\omega L - \frac{1}{\omega C_{ext}}\right) \quad (1)$$

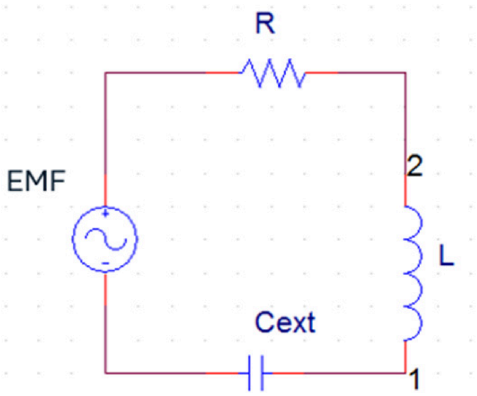
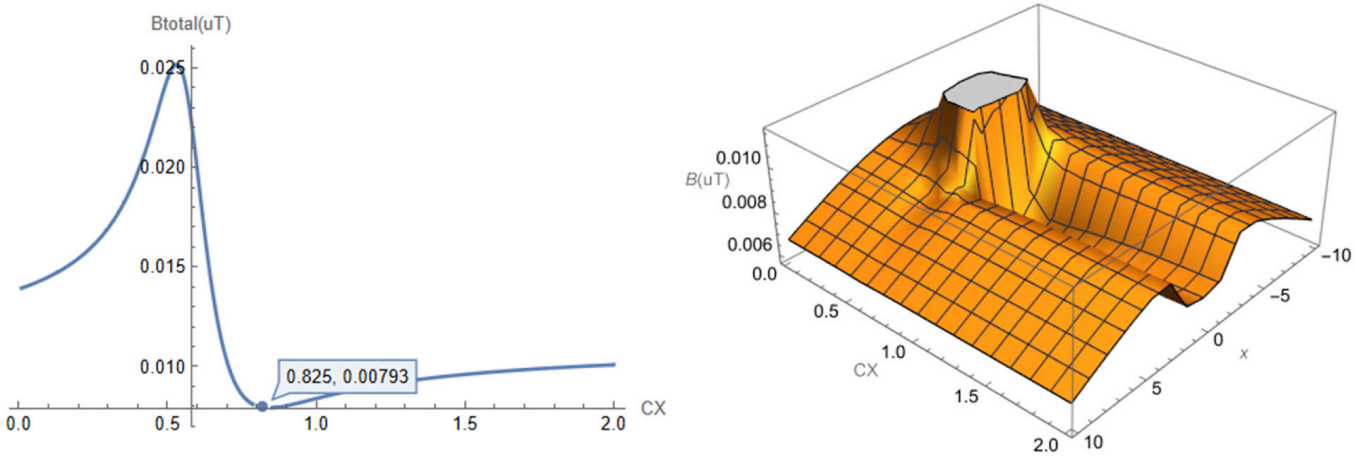


Figure 2. Equivalent electrical circuit with an external capacitor.

However, it must be kept in mind that although the series resonance phenomenon leads to an increase in the value of the induced current in the loop, the usage of external capacitances as additional reactive elements leads to a change in the phase of the induced current. This phase change is also transmitted to the expression/shape of the reaction magnetic field, a field which may therefore have not the maximum efficiency in the magnetic field mitigation below the passive loop. Thus, for the medium voltage line (conductors placed in line), the value of the external capacitor was calculated using the Wolfram Mathematica software—V13.3 [14], finding the most suitable value for the proposed application (Figure 3).



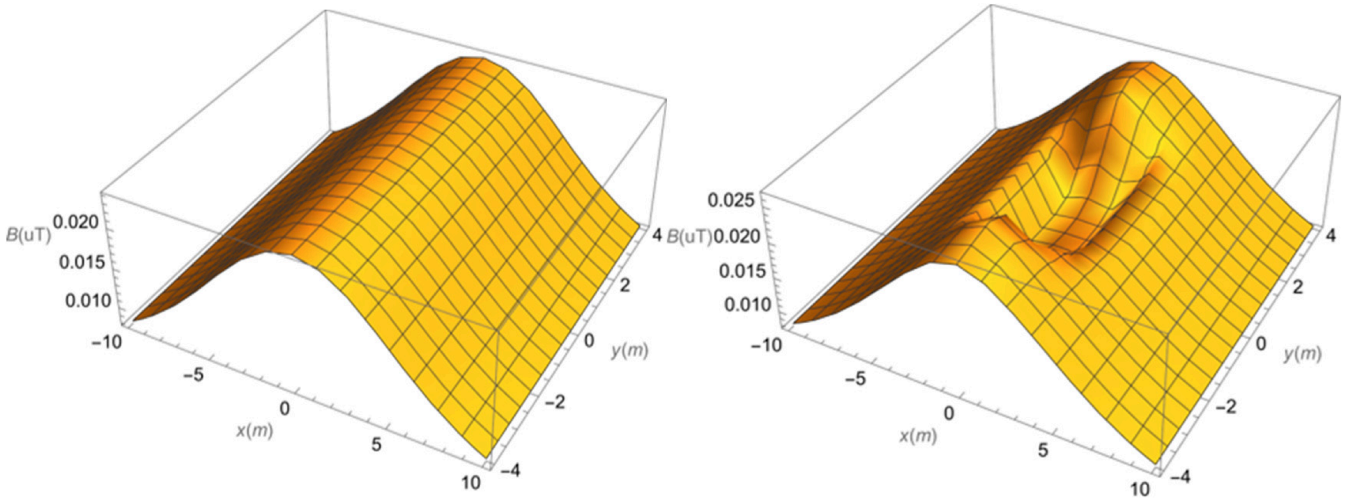
(**a**) (**b**)

Figure 3. (**a**) Variation graph according to capacitance in F (2D); (**b**) 3D representation based on capacitance value and x-axis in m.

3. Results and Computational Analysis

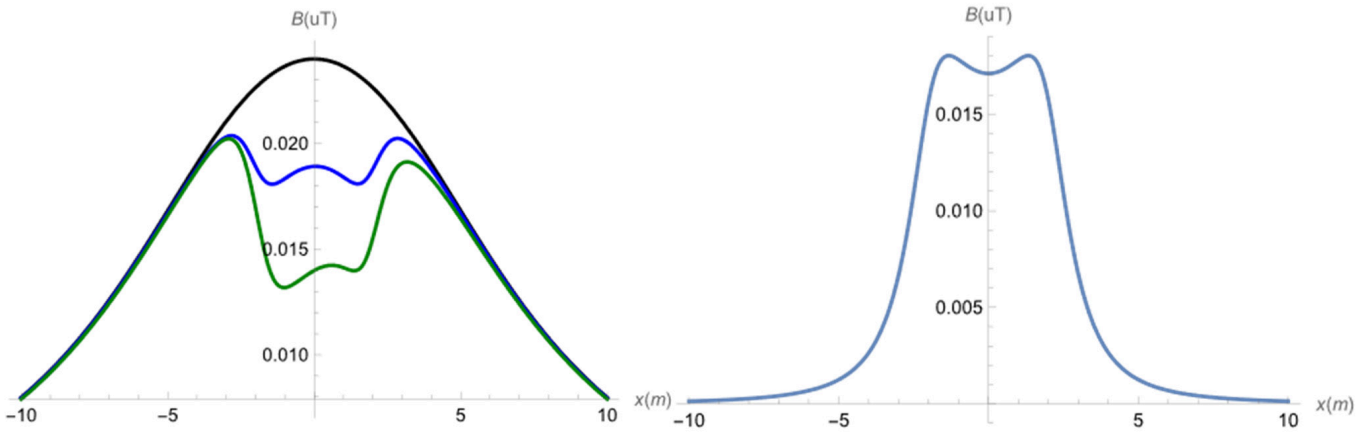
The study considered refers to the three-phase electric line with conductors placed in line shown in Figure 1a. For this application, the three conductors are considered to be placed at a distance of 3 m from each other, at a height of 10 m from the ground. The length of the conductors, considered to be placed symmetrically with respect to the 0y axis, is 200 m. The rectangular loop, with dimensions 4 × 4 m, is placed symmetrically with respect to the 0x and 0y axes, at a height of 5 m from the ground. It is specified that these numerical data were used and correspond to the realization of the variation graph of the EMF induced in the loop with respect to its position on the 0x axis direction shown in Figure 1b. The case analyzed and presented below aims at positioning the passive loop corresponding to the maximum position of the EMF induced in its sides according to Figure 1b, namely symmetrically with respect to the 0x and 0y axes, at the specified height above the ground.

The use of an external capacitance, in this case Cext = 0.8 F (according to numerical analysis from Wolfram Mathematica software—V13.3), leads to a substantial improvement in the suppression of the magnetic field by the passive loop, as can be seen in Figures 4 and 5. Thus, the maximum mitigation in the magnetic field values under the passive loop increases from 21.7% in the case of a single loop without an external capacitor to 43.5% with a single loop with the external capacitor. In this context, it is found that the use of an external capacitance (value 0.8 F) in the case of the application where a three-phase electrical line with in-line conductors is considered represents an efficient solution for the suppression of the magnetic field in the space under the passive loop.



(**a**) (**b**)

Figure 4. Distribution of the magnetic field B [uT] in the vicinity of the conductors (**a**) 3D result without a passive loop; (**b**) 3D result with a single passive loop and Cext.



(**a**) (**b**)

Figure 5. (**a**) Magnetic field distribution with and without external capacitance, in cross section; (**b**) The self-generated magnetic field of the passive loop, in section, with external capacitance.

For all the cases as a color plot with black represents the initial field without a loop, with blue represents the usage of a single loop, and with green represents the single loop with the external capacitance (Cext).

The second study considered refers to a three-phase high voltage (110 kV) electrical line with a single circuit having the support pole configuration shown in Figure 6. Considering the effective value of the current through the line, Is = 1 A, the phase arrangement in Figure 6, respectively, the loop placed symmetrically with the pole axis at a height of 10 m from the ground, the rectangular loop having dimensions of 4 × 4 m [13].

The use of external capacitance is also efficient in this case. Thus, using the value Cext = 0.8 F, the effect of its presence in the passive loop circuit is shown in Figure 7a,b the distribution of the loop's own magnetic field in this case is shown.

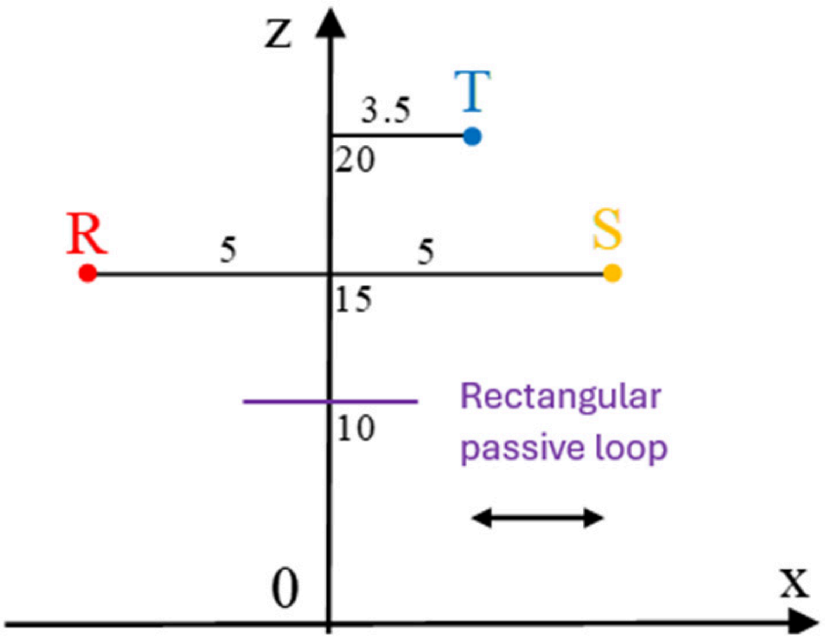
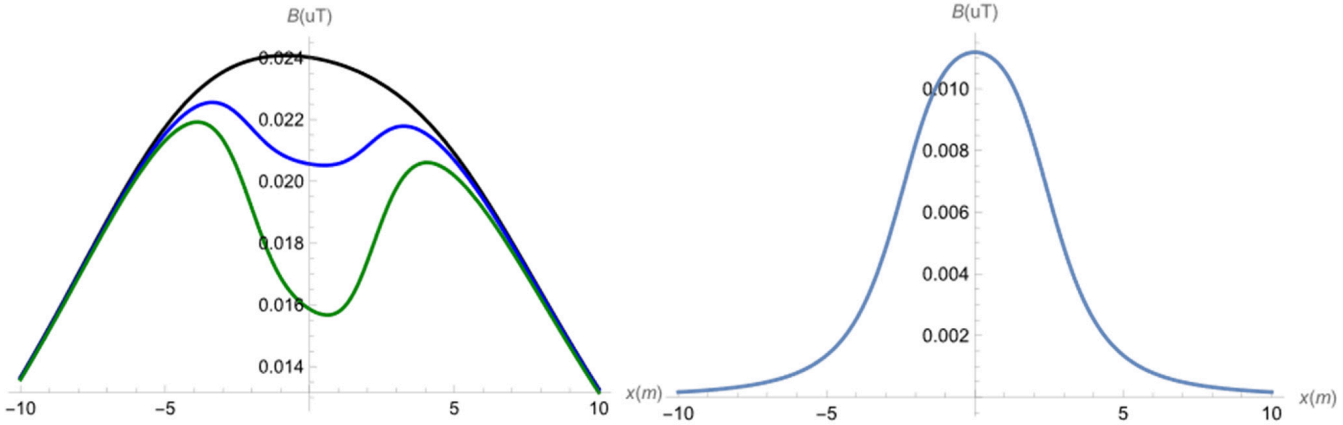


Figure 6. Pole configuration for a 110 kV single-circuit transmission line with a single rectangular passive loop (4 × 4 m).



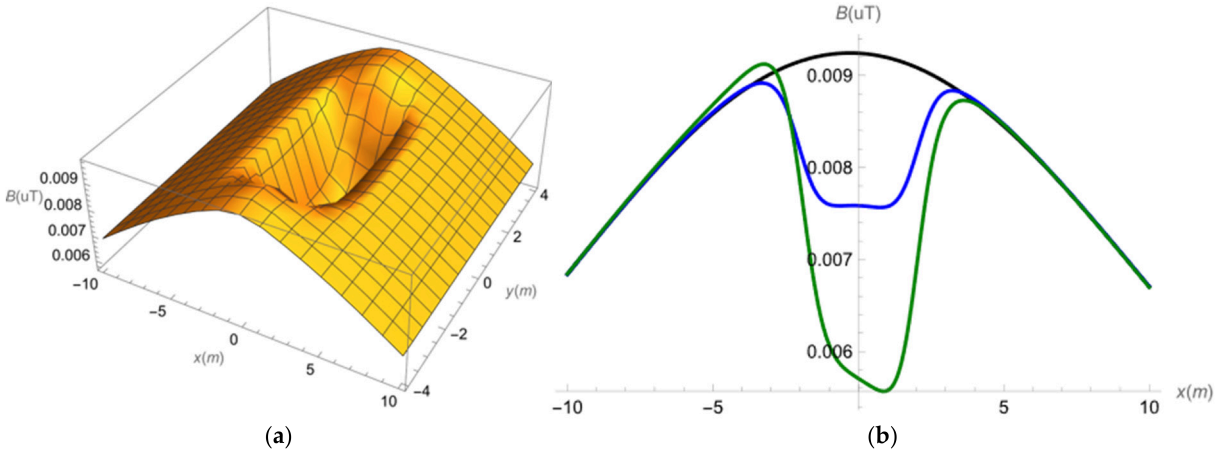
(**a**) (**b**)

Figure 7. (**a**) Magnetic field distribution with and without external capacitance, in cross section; (**b**) The self-generated magnetic field of the passive loop, in section, with external capacitance.

According to Figure 7, the effect of the presence of the external capacitance leads to a mitigation of the magnetic field in the proposed area under the loop of up to 33%, while without its presence, the maximum mitigation effect is only 14%.

In practical situations, the magnetic field distribution at a height of 1.8 m (the height of study regarding the influence on humans) is of interest. Thus, for the example described above, the variation of the magnetic field with and without the presence of the loop, with and without the existence of the external capacitance, is presented in Figure 8.

It is clear that the positioning of the passive loop in relation to the targeted area for magnetic field suppression plays a decisive role in achieving the desired effect. For the example considered, if the passive loop is placed at a height of 3 m from the ground, its effect at a height of 1.8 m above the soil, as the requirements of Transelectrica SA, TSO Company is the one presented in Figure 8, without and with the use of the external capacitance of 0.8 F, respectively.



(**a**) (**b**)

Figure 8. Magnetic field distribution B [uT] in the vicinity of the three-phase power line, at a height of 1.8 m above the ground, with the passive loop positioned at 3 m above the ground and external capacitance (**a**) 3D representation; (**b**) 2D representation.

It is found that reducing the height of the loop placement contributes substantially to the mitigation of the magnetic field in the specified area, namely at 1.8 m from the ground. Thus, using only the passive loop (without external capacitance), the mitigation effect reaches a maximum value of 18%, and in the case of using external capacitance, the mitigation efficiency increases to 40%.

4. Conclusions

Simulation results show that passive loops are an effective solution for mitigating power frequency magnetic fields generated by high-voltage overhead power lines. Configurations in which the loop is located closer to the ground show superior efficiency compared to arrangements located at higher positions. In addition, the integration of an external capacitor contributes significantly to the improvement of magnetic field mitigation performance.

Certainly, this is a future discussion; positioning the loop for maximum efficiency for magnetic field suppression under predetermined conditions is the subject of optimal design applications.

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