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REDUCING THE MAGNETIC INDUCTION INSIDE AND OUTSIDE MEDIUM AND HIGH VOLTAGE SUBSTATIONS

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Convergence of studies and therefore of international scientific conclusions point to a negative impact of the magnetic component of the electromagnetic field created by electricity transmission and distribution installations under residential and occupational exposure conditions. The paper will highlight a number of solutions to reduce magnetic induction inside and outside electrical transmission and distribution stations, especially in urban areas.

Keywords: electromagnetic field, magnetic induction, electrical transmission and distribution substations

1. Introduction

Given that the magnetic induction corresponding to an electrical substation at a given calculation or measurement point results from the phase summation of the partial magnetic induction created by the various current-carrying elements of the electrical substation in question, it is not possible to indicate a single solution for reducing the magnetic induction, either inside or outside the substation [1, 2, 3]. It is very important to establish from the start certain areas of interest in which to reduce the magnetic induction values below a certain threshold, such as areas where there is a very high probability of exposure of the population: houses, economic and administrative headquarters, schools, roads etc. It is mentioned that a global solution to reduce magnetic induction everywhere, indoors and outdoors, would be theoretically possible, but becomes economically onerous [4, 5, 6].

The solutions for reducing magnetic induction are different and apply to specific cases as described below.

2. Shielding with Conductive Panels

This solution was originally designed to reduce the magnetic induction in

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the immediate vicinity of the MV/LV transformer substations, which are the most dangerous magnetic induction generating element for the population, due to the high level of induction produced, their high density in the territory and their excessive proximity to dwellings, public buildings, hospitals, hotels, access roads, etc. [7, 8, 9, 4, 10, 11, 12].

Research has shown that their efficiency is higher the higher the electrical conductivity of the constituent material, the results of which are shown in Table 1 [B13].

Fig. 1 shows the variation of the shielding efficiency as a function of the distance between the screen and the magnetic induction generator, in this case a transformer substation busbar system [13], for screens made of aluminum and steel, respectively.

Table 2 shows the results obtained for the efficiency of screening with aluminum panels of different thicknesses, finding that a thickness of 3mm is optimal in terms of cost-effectiveness [13].

Tests conducted with double screens made of steel and aluminum panels have shown that better efficiency is obtained if the panel with higher conductivity (aluminum) is placed towards the induction source and the distance between panels is very small, e.g., 1mm.

The solution of shielding the magnetic induction generating elements can also be applied in the case of HV substations, i.e., by cladding the inner substation walls, placing shielding panels in front of the rigid busbars and power transformers, towards the outer substation fences, in order to reduce the magnetic induction outside the substation [14, 15].

Table 1

Screening efficiency depending on materials used [B13]

Material	Conductivity σ (Sm-1)	Relative permeability μr	Screening efficiency
Al	3,77	1	10,49
Cu	5,98	1	11,22
Ag	6,29	1	11,28
Fe	1,03	500	3,67
Fe	1,03	1000	2,45
Fe	1,03	2000	1,49

3. Optimal Phase Arrangement and Compaction of the Phases

The optimal arrangement and compaction of the phases is a very efficient solution to reduce both electric field strength and magnetic induction. This solution was originally designed for overhead high voltage power lines [16, 17, 18, 19].

Fig. 2 shows the variation of electric field strength and magnetic induction in a cross-section on a 400 kV double-circuit overhead line with symmetrical phase arrangement and optimal phase arrangement, respectively. It can be seen that at a distance of 50 m from the axis of the line, the magnetic induction is reduced from 2 to 0.4 μT, the measurements made confirming the calculations.

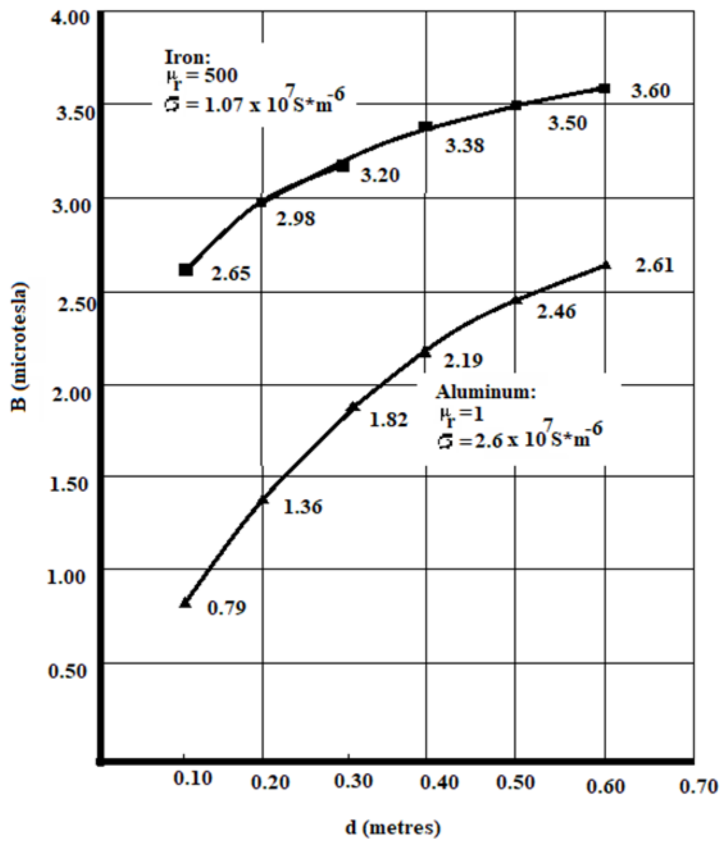


Fig. 1. Magnetic induction for two different shielding materials, Fe and Al, as a function of the distance between shield and bars [13]

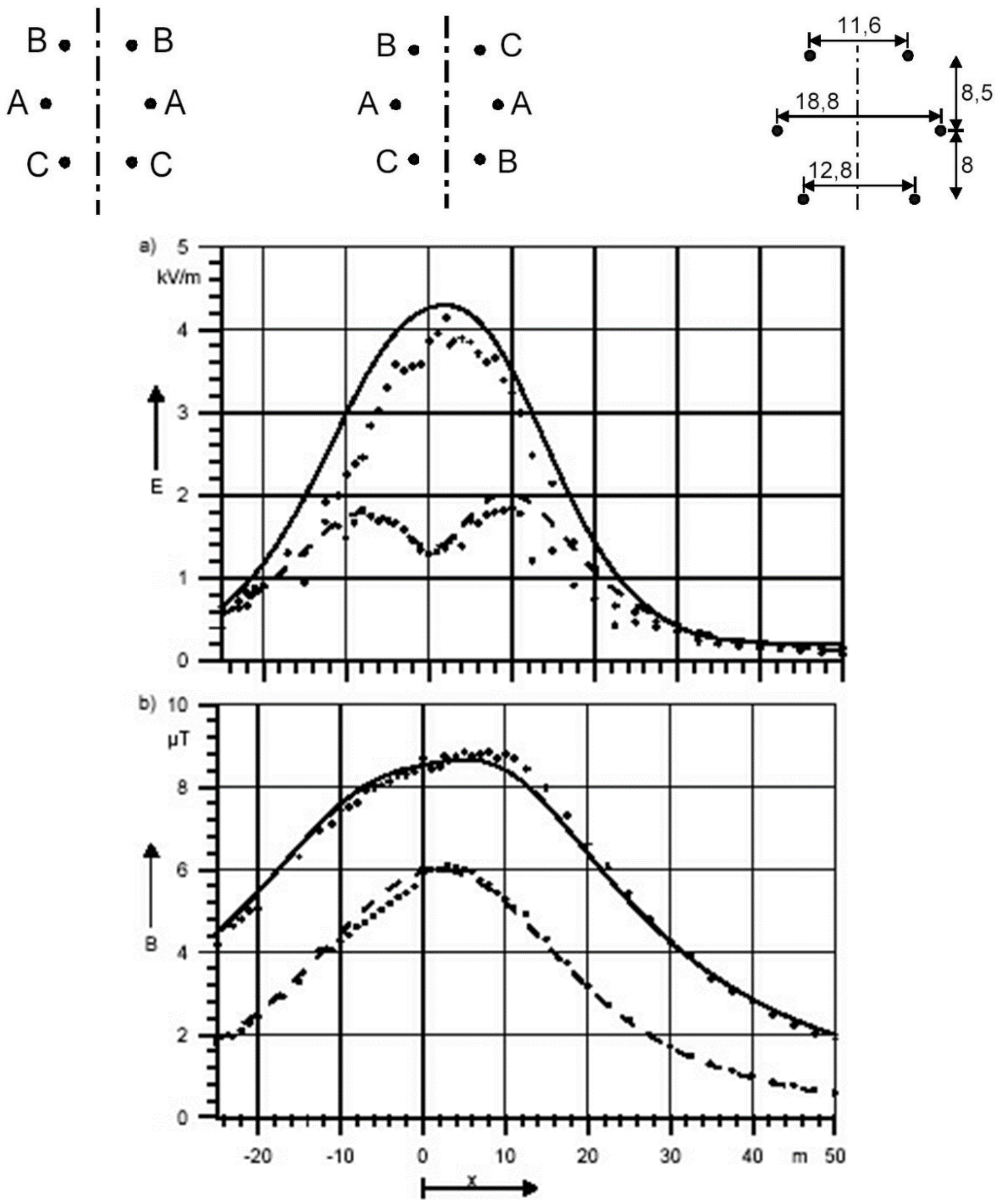
Table 2

Efficiency of screening with aluminum sheet depending on its thickness[B13]

τ (mm)	1	2	3	5	8	10	12
S	6,1	9,6	10,5	11,1	11,3	11,4	11,5

The use of a compact arrangement of a single-circuit 150 kV overhead line brings important advantages in terms of magnetic induction reduction (Fig. 3).

Symmetrical arrangement Optimal arrangement Distances between conductors (m)



Symmetrical arrangement
________________ calculates
++++++++++++++ measuring

Optimal arrangement
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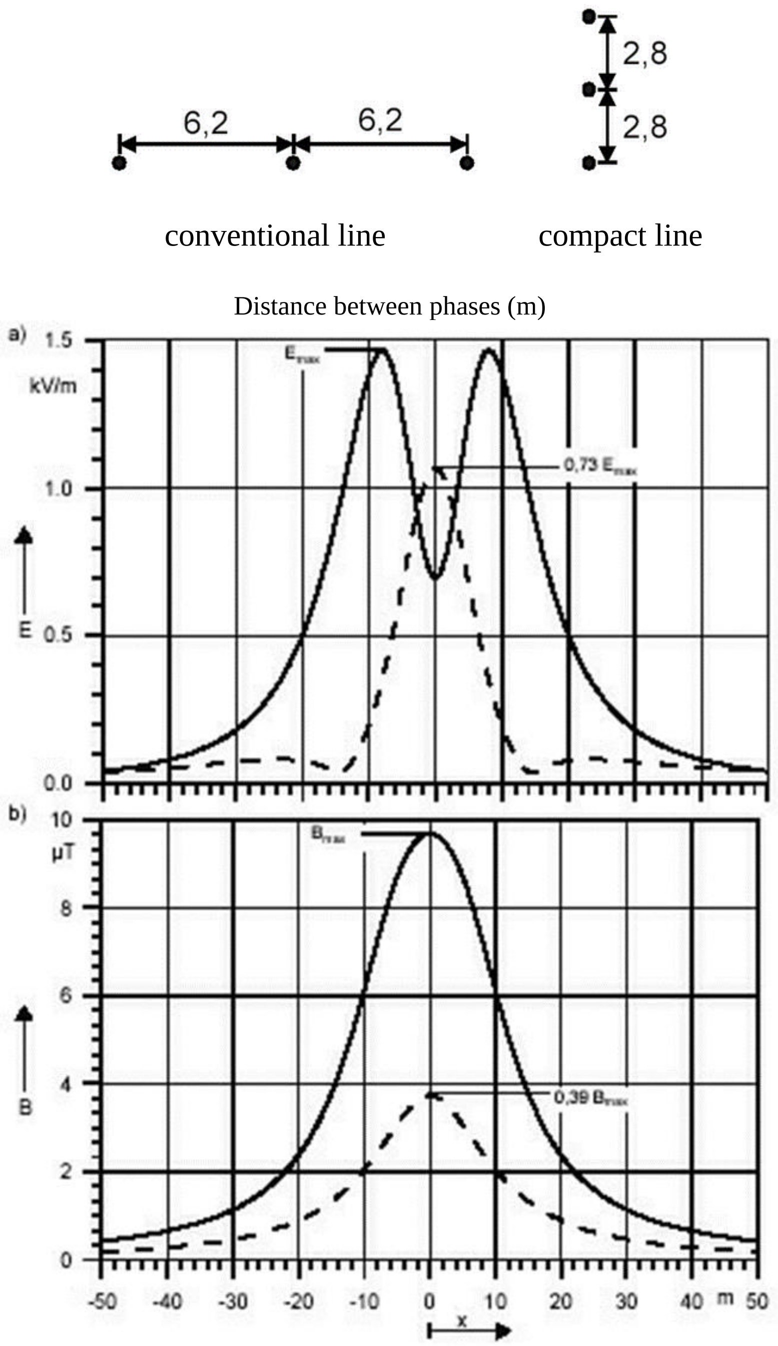
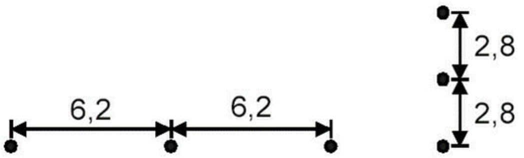
Fig. 2 Values of the **a)** electric and **b)** magnetic field under a 400 kV double circuit line with symmetrical and optimal arrangement [16]

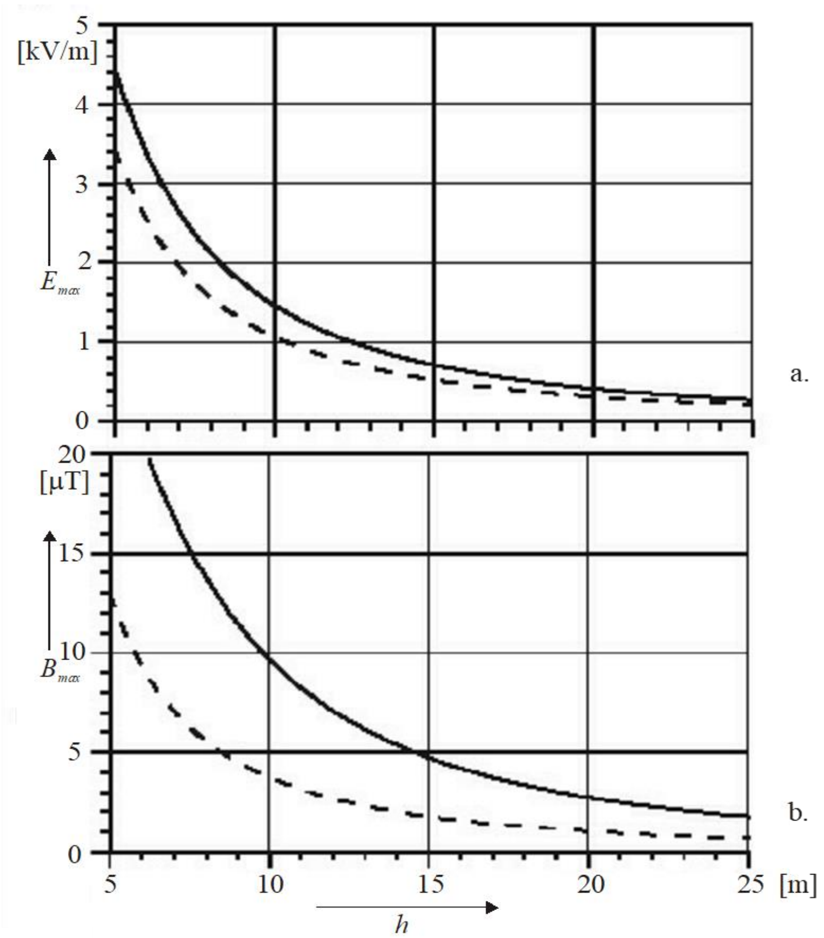


_________________ conventional line
- - - - - - - - - - - - - - compact line

Fig. 3 Diagrams of **a)** electric field intensity and **b)** magnetic induction under a 150 kV line with conventional and compact arrangement respectively [16]



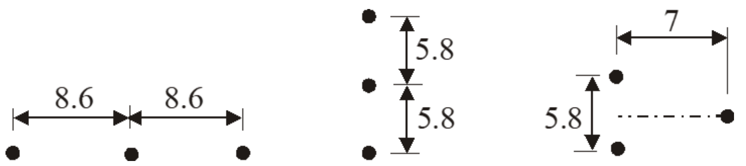
Conventional and compact canopy respectively as a function of the distance h between the lowest conductor to ground



Distance between lower phase conductors and ground (m)

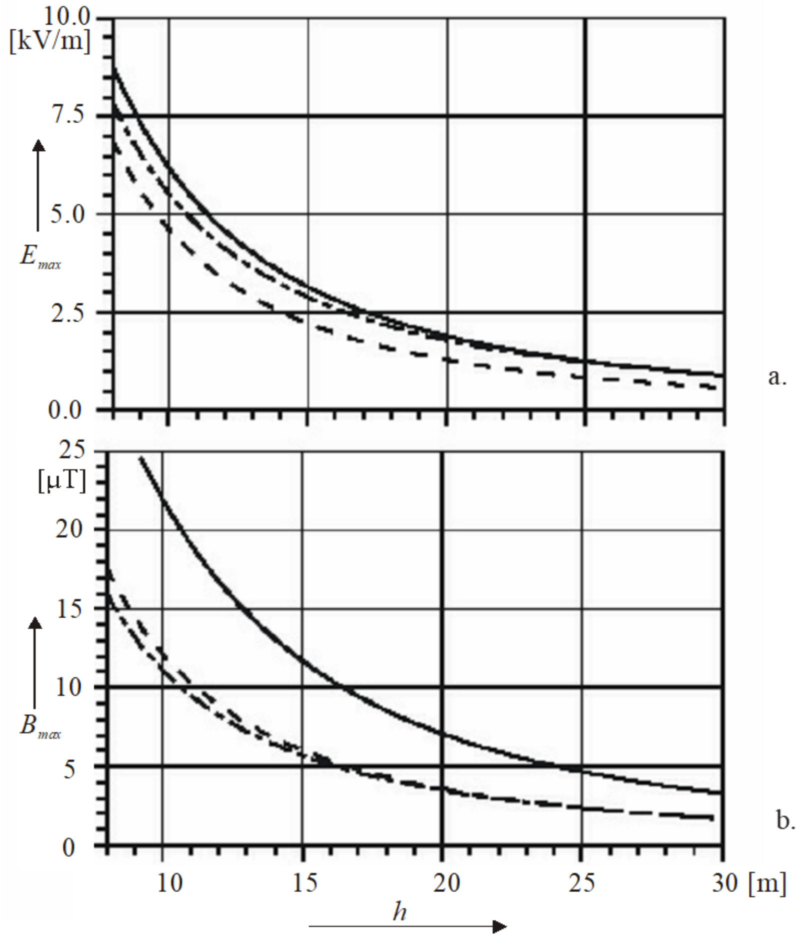
_________________ conventional line
- - - - - - - - - - - - - - compact line

Fig. 4 Values of the a) electric field intensity and b) magnetic field induction under a 150 kV single-circuit line with conventional and compact arrangements as a function of the distance h between the lowest conductor and ground [16].



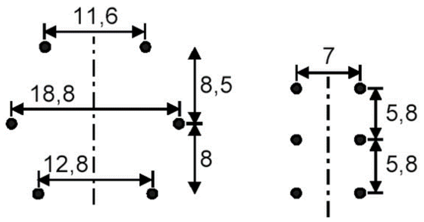
Conventional line Compact vertical line Compact triangular line

Distance between conductors (m)



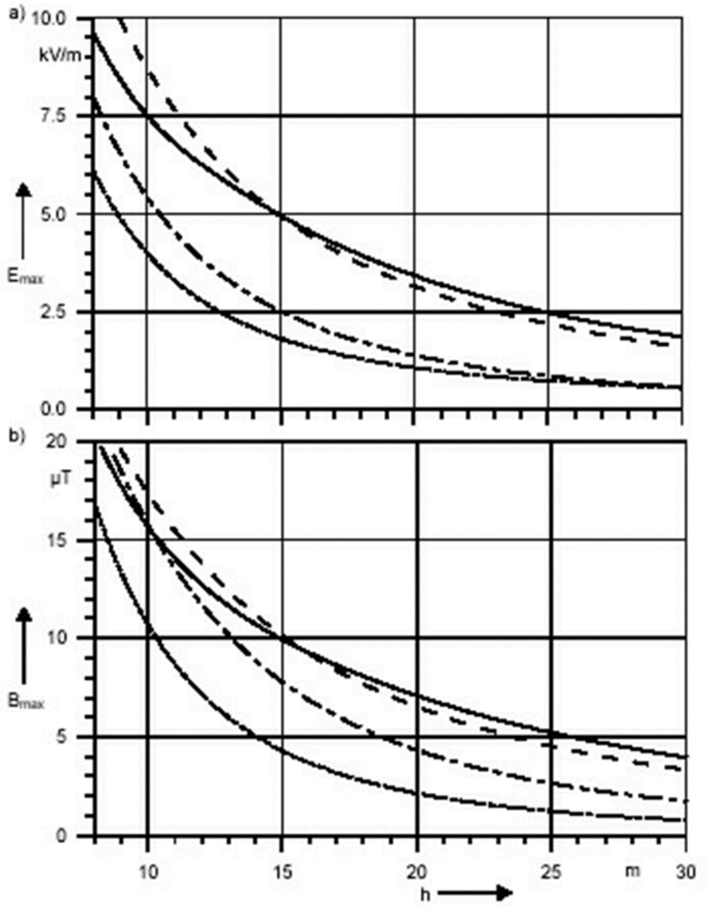
__________________ conventional line __ _ __ _ __ _ _ __ vertical compact line
_ _ _ _ _ _ _ _ _ _ _ _ triangular compact line

Fig. 5 Maximum values of the a) electric field intensity and b) magnetic field induction under a 400 kV single-circuit line with conventional and compact arrangements as a function of the distance h between the lowest phase conductor to ground [16].



Conventional arrangement Compact line

Distance between conductors (m)



Conventional line	Compact line	
______________	__ __ __ __ __ __	Symmetrical arrangement
__ _ __ _ __ _ __	_ _ _ _ _ _ _ _ _ _ _	Optimal arrangement

Fig. 6 Maximum values of a) electric field intensity and b) magnetic field induction under a 400 kV double circuit line of conventional and compact phase arrangements with phase symmetry and nonsymmetry depending on the distance h between the lowest conductor to ground [16].

Thus, in the line axis the magnetic induction is reduced by 61% and at a distance of 25 m from the line axis, the magnetic induction is reduced from 1.6 to 0.7 μT.

A significant reduction in electric field strength and magnetic induction is also achieved by increasing the ground clearance of the active conductors (Fig. 4). Increasing the ground clearance from 6 m to 15 m for the 150 kV single-circuit line reduces the magnetic induction in the line axis from 20 to 5 μT, for the line with horizontal phase arrangement and from 12.5 to 2 μT for the compact arrangement.

In the case of single-circuit 400 kV overhead power line, increasing the ground gauge of the lower active conductors from 8 m to 25 m (Fig. 5), for example, decreases the magnetic induction in the line axis from 25 to 5 μT for the horizontal canopy, from 17.5 to 2.5 μT for the compact vertical canopy and from 16 to 4 μT for the compact triangular configuration [B20].

In the case of the 400 kV double-circuit lines it is also found that increasing the ground clearance of the lower phase conductors (Fig. 6) from 8 m to 25 m decreases the magnetic inductance in the line axis from 20 to 5 μT for the lines with hexagonal phase arrangement and from 16.5 to 1.5 μT for the compact optimal phase arrangement.

The advantages of using compact arrangement in inhabited areas, as well as optimal phase arrangements, are indisputable for the high voltage overhead lines. These solutions are also applicable to the overhead connections of the lines to substations. In the calculations, to determine the optimal phase arrangements of each air connection, many variants will have to be analyzed, the magnetic induction at a given point of interest resulting from the phase superposition of the inductions of each connection [21, 22, 23].

4. Use of Passive and Active Circuits

4.1. Passive Circuits

For a 400 kV single-circuit line with horizontal phase arrangement, five possible passive circuit solutions were considered (Fig. 7) [B24]. Circuit A has been positioned at a minimum distance (d_m) from the side phase, so the induced current in this circuit is the maximum one. The circuit B has been positioned so that the magnetic induction at the edge of the ROW is minimal. The circuits C and D respectively have been formally positioned and the circuit E is positioned exactly on one of the shield wires.

The line is symmetrically loaded with 500 A per phase, the distance between two adjacent phases d= 8,5m, the distance between circuit A and the phase dm = 5m, the ROW has 25 m on either side of the line axis, the height of the conductor of circuit B is 6m, the distance between the axis of circuit B is 35 m, the conductor used for the passive circuits is ACSR HEN with an electrical resistance of 0,1229 Ω/km. From Figs. 8 and 9, it can be observed a significant reduction outside the line corridor, for example 50 m from the line axis, if applying variants, A and B, with reductions of 30 and 25%, respectively.

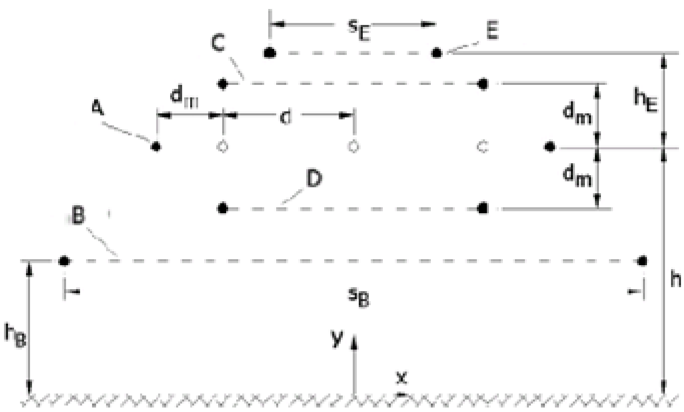


Fig. 7 Different loop solutions for the horizontal phase configuration line [24].

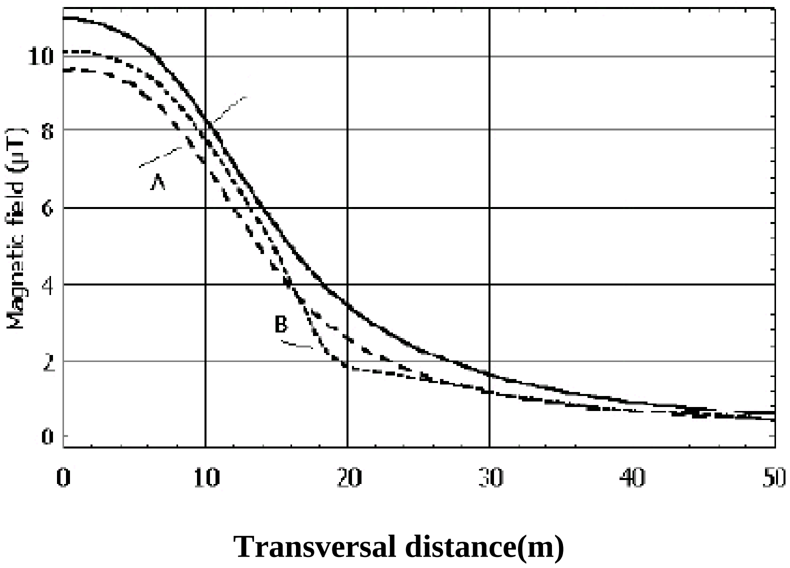


Fig. 8 Magnetic induction without loop and with loops A and B, for horizontal phase configurations (without compensation)

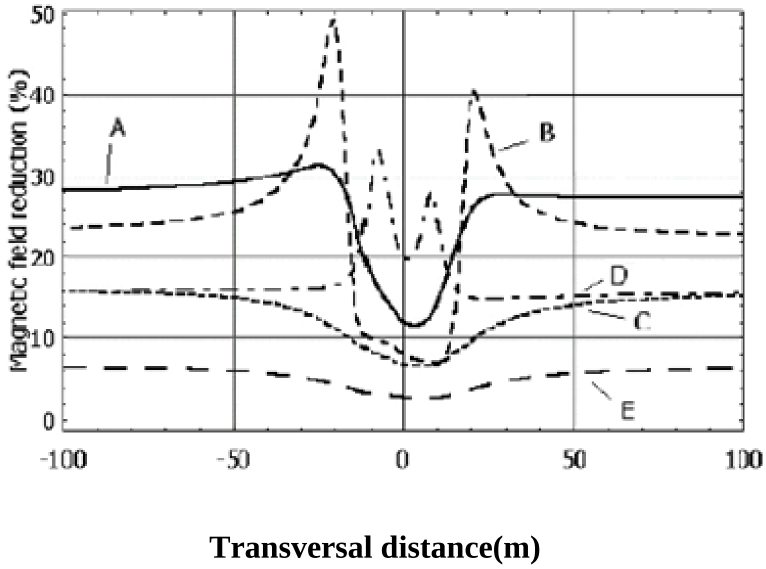


Fig. 9 Magnetic field reduction using different passive loop solutions (A, B, C, D, E) [24]

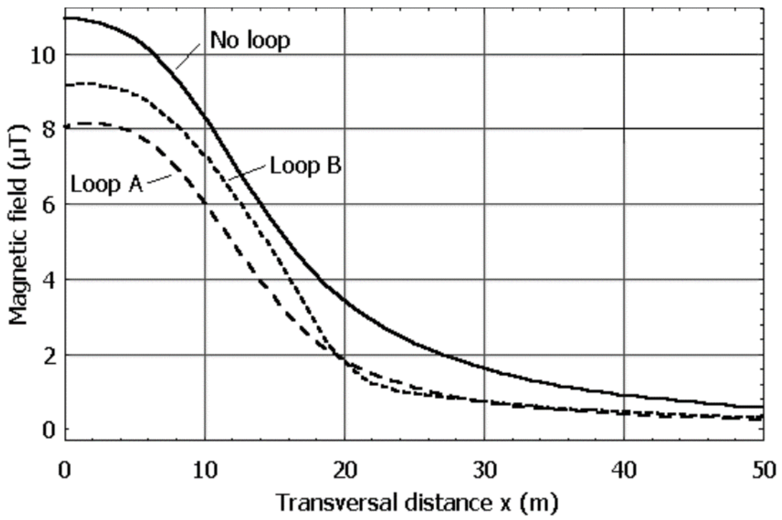


Fig. 10 Magnetic induction, without loop and with compensated A and B loops, with horizontal phase configurations [24]

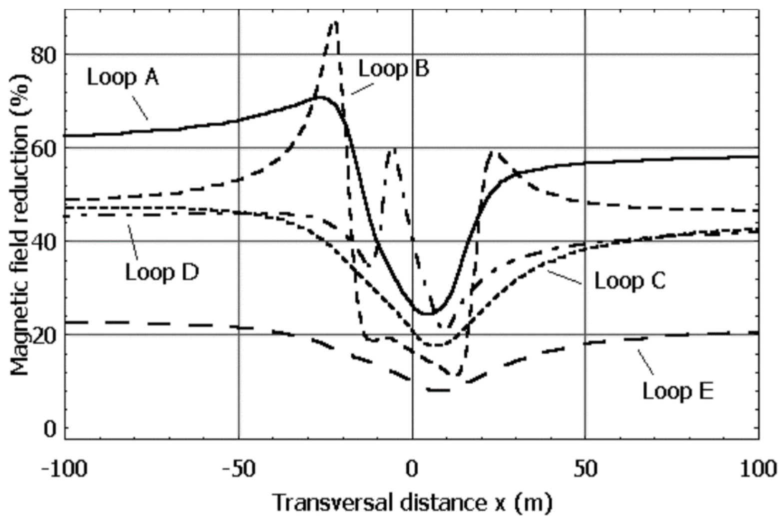


Fig. 11 Magnetic induction reduction with different compensated loops and horizontal phase configurations [B24]

4.2. Compensated Passive Circuits

Considering the same electric line described in 4.1. and the same passive circuit variants but inserting capacitors in these passive circuits. Their reactive power is determined according to the load of the power line and the geometrical position of the circuit under consideration [24]. The conductors of passive circuits must have a higher conductivity than in the case of simple passive circuits. Therefore, the ACSR RAIL conductor with an electrical resistance of 0.06/kmΩ was considered. The reactive capacitor powers are between 5.4 and 42.1 kVAr/km. The lowest powers correspond to variants B, 5.4 kVAr/km and A, 18 kVAr/km.

From Figs. 11 and 12, it can be seen that the circuits corresponding to the compensated variants A and B reduce the magnetic induction at the edge of the lane from 2.2 to 1 µT, and at 50 m from the line axis the magnetic induction reaches less than 0.7 µT. Variant A appears to be more effective in reducing magnetic induction at distances greater than 35 m from the line axis (60-65%), while variant B is more effective in reducing magnetic induction at the ROW edge (85%).

4.3. Active Circuits

Considering the same 400 kV single-circuit line and the same geometrical positioning of the circuits in those five variants, as described in 4.1. and 4.2., the only difference being that currents are injected into the active circuits from external sources, the size and phase shift of these currents depending very much on the line loading, the type of circuit and the distance from the axis of the line at which the best reduction effect is desired [24].

The necessary electric power varies in the range 1.4- 63.3 kW for a span of 450 m [24], the lowest corresponding to the variants A (4- 4.8 kW) and B (1.4- 2.4 kW) respectively. Fig. 12 shows the magnetic inductance reduction diagrams as a function of transverse distance from the line axis for all five compensated circuit variants, where the aim is to achieve a massive reduction in magnetic inductance at the edge of the ROW (25 m from the line axis). Fig. 13 shows the diagrams of the magnetic inductance reduction as a function of the transverse distance from the line axis in the five active circuit variants, where the magnetic inductance reduction is aimed at large distances from the line axis. It is found that, generally, the maximum reduction is obtained with A circuit type.

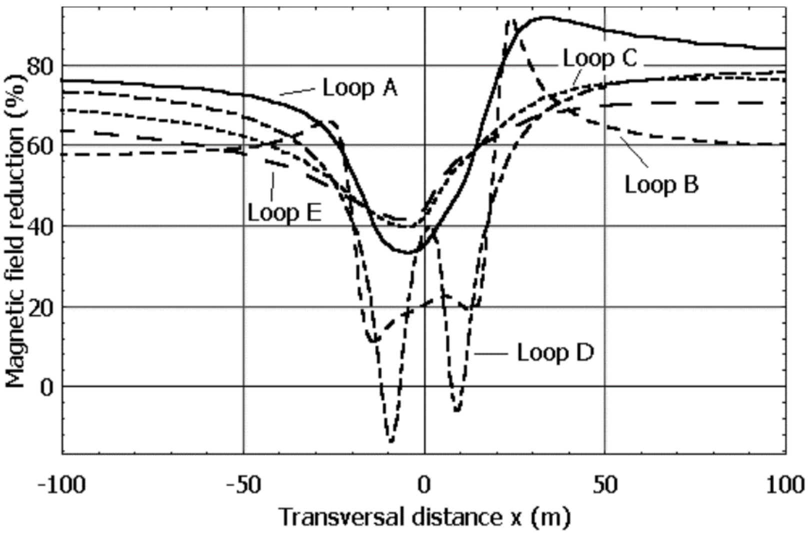


Fig. 12 Magnetic field reduction using active loops and x_0 = 25 m[B24]

4.4. Assessments of the Applicability of Passive and Active Circuits

In choosing one of the presented options, in terms of reducing magnetic induction, the installation costs, the electricity costs, if any and of course the visible environmental impact should be considered. As it is impossible to satisfy all these criteria to the superlative, a compromise must be found for each individual case. In any case, of the five geometric variants, variants C, D and E should be eliminated, as they are inefficient in all the kinds: passive, passive with compensation and active. From the point of view of the environmental impact, the variant B is very harsh, involving the erection of 6 m high poles in the ROW and therefore is recommended to be eliminated. Under these conditions, only the variant A is left to be analyzed in the three technological solutions, passive,

passive with compensation and active respectively, with the related installation and operating costs. The choice of one of these variants is dictated by the magnetic induction calculated or measured in the areas of interest in the absence of the reducing circuit, and the solution which reduces the magnetic induction to the level considered necessary to be adopted. The application of the passive or active circuit solutions is particularly effective in the case of connections to electrical substations but can also find application in the case of external substation busbars [20], [25].

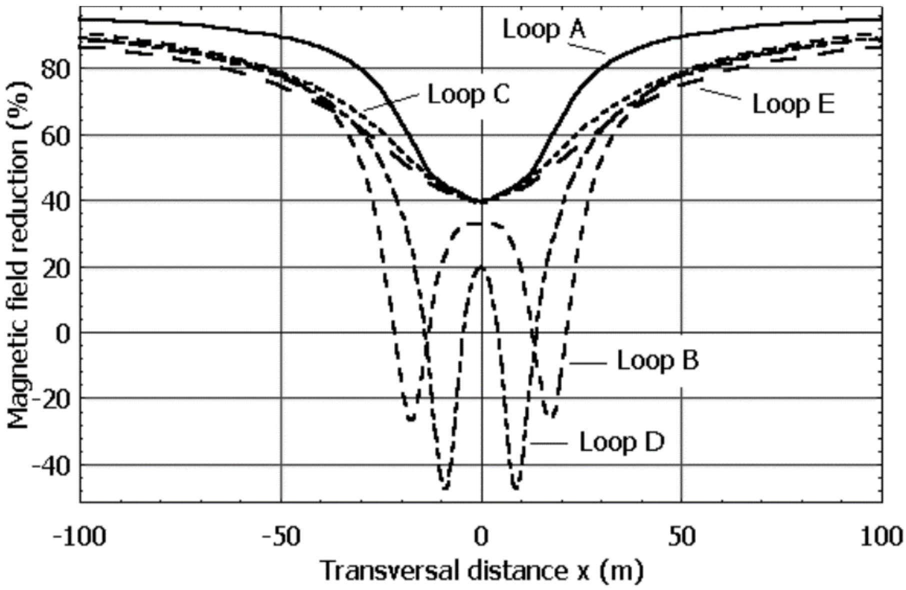


Fig. 13 Magnetic field reduction with active loops and infinite x_0 [B24]

5. Conclusions

From the point of view of electric field, generally, the maximum limit recommended by ICNIRP of 5 kV/m is not exceeded outside the substations, the only places where it could be exceeded being in the ROWs of the connecting power lines, where normally, according to the regulations in force, the construction of private or public buildings is not allowed. From the point of view of the magnetic induction, the limits considered in some countries, in the range 0.2 - 1μT can be exceeded and reduction measures must be considered.

The reduction measures should be applied to each building element of the station, the following ones being recommended:

- overhead electrical connections:
  - optimal arrangement of phases;
  - compacting of the tower top geometry in the area of interest;
  - increase the ground clearance of the lower phases;
  - installing passive or active circuits in the area of interest;

- flexible bars:
  - optimal arrangement of phases;
- rigid bars:
  - optimal arrangement of phases
  - screening with high panels made of sheet metal aluminum;
- power transformers:
  - layout with optimal phase arrangement;
  - screening with high panels made of aluminum;
- station building:
  - screening of the building walls with aluminum sheets;
  - compact the cables, replacing the single-phase cables by three cores ones.

The above-mentioned criteria should be taken into consideration during the design phase of new stations as well as during the design phase of major repairing or existing stations retrofitting.

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