Optimum Conductor Arrangement of Compact Lines for Electric and Magnetic Field Minimization – Calculations and Measurements

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ABSTRACT: The optimum phase conductor arrangement and the compaction (dimension reduction) as measures for the minimization of electric and magnetic fields of 400kV double circuit lines are examined. Computation results showed that the combination of compaction and optimum arrangement causes a drastic electric and magnetic field reduction. However, if the optimum arrangement is not used, the field values produced by the compact line are similar to those produced by the conventional (not compacted) one.

Measurements made before and after the application of the optimum phase conductor arrangement confirm the drastic reduction of the electric and magnetic field values. The application oft he optimum arrangement to a compact 400kV line made possible the reduction of the electric and magneticf ield values to similar values as those produced by a 125kV line.

Keywords: Overhead Transmission Lines – Compact Lines – Optimum Arrangement – Electric Field Reduction – Magnetic Field Reduction

I INTRODUCTION

In ICNIRP Guidelines [1], ther eference levels for general public exposure to 50Hz electric and magnetic fields are 5kV/m and 100μT respectively. These values are the same as those adopted in the corresponding European Board Recommendation [2]. The values of magnetic field flux density at places accessible to general public, under overhead lines, are as a rule much lower than 100μT, independently of the line voltage. However, if the line voltage is greater than 220 kV, the electric field intensity at these places may exceed 5kV/m.

The phase conductor arrangement of double circuit overhead lines is an important factor for the electric and magnetic levels around them. The optimum phase arrangement of double circuit lines for the electric and magnetic field minimization was investigated in [3] and [4]. The symmetrical and the optimum phase conductor arrangement of double circuit power lines are shown in figure 1. The symmetrical arrangement is the one thath ad been used in the existing 400kV double circuit lines of the Greek Transmission system. In order to minimize the electric and magnetic field values at the environment of these lines the optimum phase conductor arrangement is applied. Measurement of the electric and magnetic field levels before and after the optimum arrangement application was made and their results are presented.

Besides the optimum arrangement, compaction (dimension reduction) is another way to reduce the electric and magnetic field levels around power lines, [5], [6]. The electric and magnetic field levels around a 400kV conventional line and a corresponding compacto ne are examined for the symmetrical and the optimum phase arrangement.T he conventional line is shown in figure 2a and the compact one in figure 2b. Figures 2a and 2b are under the same scale and so the great reduction of the optical impactdu e to the compaction is obvious.

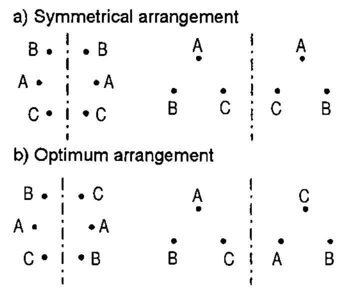

Fig. 1. a) The symmetrical phase conductor arrangement and b) the optimum phase conductor arrangement for electric and magnetic field minimization.

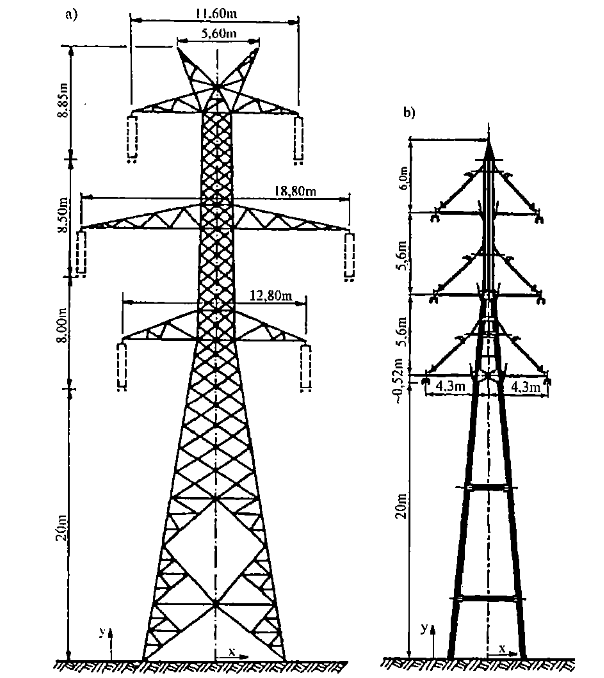

Fig. 2. Towers of examined power lines

a) conventional 400kV line of the Greek system

b) compact 400kV line

Note: The phase conductors are Al/St 2x483/63mm^2 fort he conventional line and Al/St 2x748/97mm^2 fort he compact line. Sub-conductors pacing is 40cm for both lines.

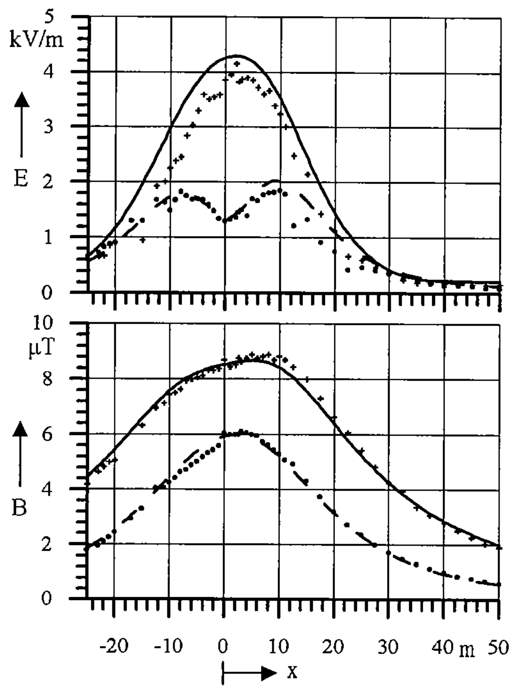

Fig. 3. a) Electric and b) magnetic field values under a 400 kV line (Fig.2a) before and after the optimum arrangement (Fig 1).

Symmetrical arrangement (before)	Optimum arrangement (after)
——— Calculations	— — — Calculations
+ + + + Measurements	• • • • Measurements

The effectiveness of the optimum arrangement and compaction in electric and magnetic field minimization under new power lines is checked by their maximum values and two other secondary metrics. These are the necessary ROW (Right Of Way) width, so that the magnetic field values outside the ROW do not exceed a given value and the necessary tower height, so that the maximum field values do not exceed given values.

As an example of the efficiency of the optimum arrangement applicationt o minimize electric and magnetic fields under compact lines, the field levels under a constructed 400kV compact line in Switzerland is investigated and compared to the levels of an existing 125kV line.

II OPTIMUM ARRANGEMENT APPLICATION

Figure3 shows them easured and calculated values before and after the application of the optimum arrangement to a Greek 400kV line (Fig. 2a). The initialp hase arrangement of this line was symmetrical one (Fig. 1). At the place of measurement the distance of the lower conductors to ground was 17,7m for the one system and 16,7m for the other. The difference is due to ground inclination. The measurement height was 1,5m. The results refer to 1000A current, which was used for the calculations as well.

The drastic electric and magnetic field reduction caused by the application oft he optimum arrangement was verified. It should be noted that the application of the optimum phase conductor arrangement was an easy process, achieved by proper interchanging of the phase conductors between the end tower and the substation.

III COMPUTATIONAL INVESTIGATION

Figure 4 shows the electric and magnetic field values under the double circuit 400kV conventionala nd compact line (Fig. 2) with the symmetricala rrangementa nd for lower conductor to ground distance h = 10m. The comparison of the curves results that, in the case of the symmetrical arrangement, electric or magnetic field values produced by the two lines are similar. Figure 5 shows the electric and magnetic field values in correspondence to Fig. 4, but with the optimum arrangement instead. Figure 5 results show that in this case compaction causes a drastic reduction of electric or magnetic field values. Also the comparison of Fig. 4 and Fig. 4 results show that the application of the optimum arrangement to a compact line causes greater reduction of electric and magnetic field values than it causes to a conventionalo ne.

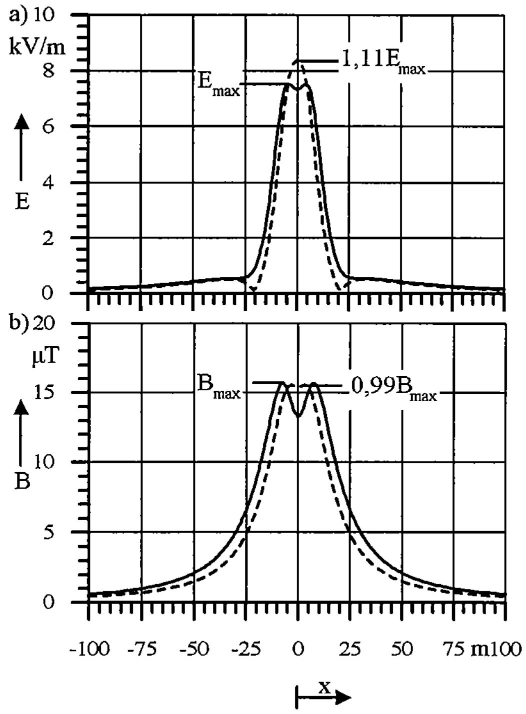

Fig. 4 a) Electric and b) magnetic field values under double circuit 400kV conventional and compact line for the symmetrical arrangement, asf unctions of the horizontal distance x from the line axis (considered currents 1000A, calculation height y = 1m).

——— Conventional line
– – – Compact line

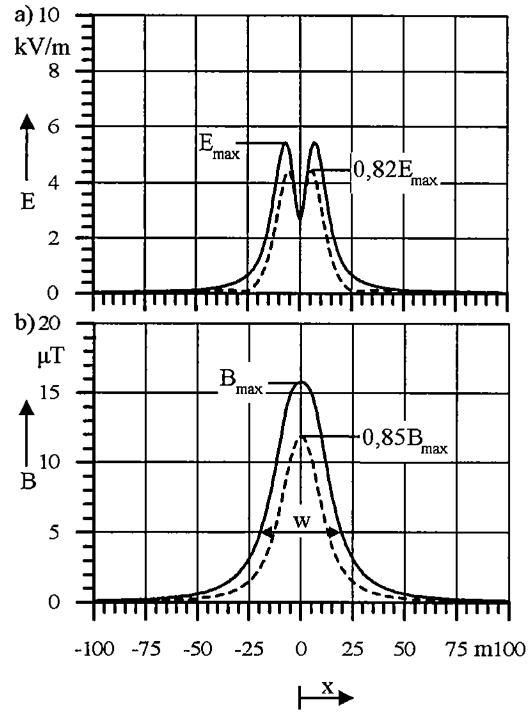

Fig. 5 a) Electrica nd b) magnetic field values under double circuit 400kV conventional and compact line for the optimum arrangement, as functionso f the horizontal distance x from the line axis (considered currents 1000A, calculation height y = 1m).

——— Conventional line
– – – Compact line

Fig. 5b also shows a graphical definition of the necessary ROW (Right Of Way) width w, so that the magnetic field values outside the ROW do not exceed an example reference value of 5µT for the conventional line with the optimum arrangement. Figure 6 shows the necessary ROW width so that the magnetic field values outside the ROW edge do not exceed reference values for the conventional and the compact line, for the symmetricala nd the optimum arrangement as a function of the reference value. The necessary ROW width is reduced by the application of the optimum arrangement for both conventional and compact lines. For example for B_{ref} = 1µT the necessary ROW width w is reduced by the application of the optimum arrangement from 150m to 80m for the conventional line and from 124m to 60m for the compact line.

Figure 7 shows the electric and magnetic field maximum values under thed ouble circuit 400kV conventional and compact line with the symmetrical and the optimum arrangement as functions of the lower conductor to ground distance h. Figure 7 expands the results occurred from Figures 3 and 4 for different line heights. This figure can be used to obtain the necessary lower conductor to ground distance h, so that the maximum field values do note xceed given values. Table 1 shows the necessary lower conductor to ground distance, h so that the maximum electric field value, E_{max} does not exceed 5kV/m. From Table 1 it can be seen that the necessary height for E_{max} = 5kV/m is drastically reduced by the application of the optimum arrangement [(1) → (2) and (3) → (4)]. Compaction to lines with the symmetrical arrangement does not reduce the necessary height [(1) → (3)]. Compaction to lines with the optimum arrangement causes a greater reduction of the necessary height [(1) → (4)]. These reductions arev ery important because they can be considered as tower height reductions.

Table 1.

Necessary lower conductor to ground distance h, for E_{max} = 5kV/m.

Conductor arrangement	h
(1) Conventional symmetrical	14,9m
(2) Conventional optimum	10,5m
(3) Compacts ymmetrical	14,9m
(4) Compacto ptimum	9,4m

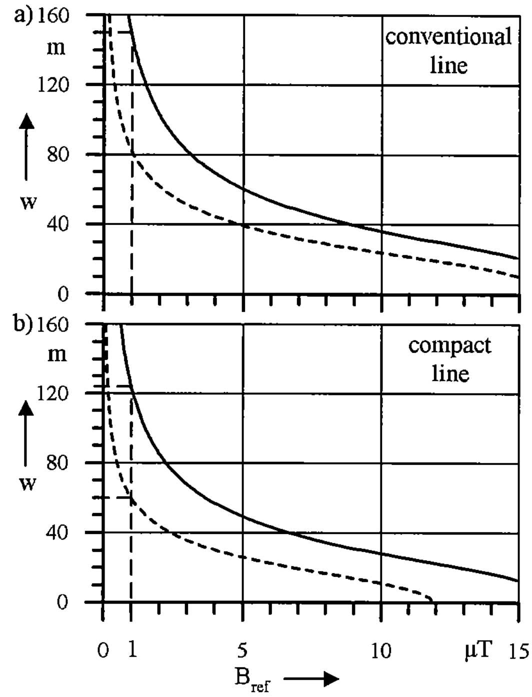

Fig. 6. Necessary ROW width w, so that the magnetic field values outside the ROW do not exceed the reference value B_{ref} as functions of B_{ref} fora) the conventional and b) the compact line witht he symmetrical and the optimum arrangement (considered currents 1000A, calculation height y = 1m).

——— Symmetrical arrangement
-------- Optimum arrangement

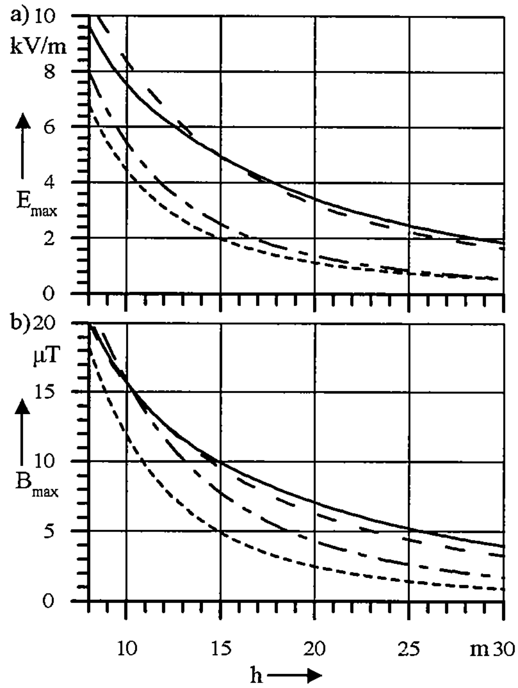

Fig. 7 a) Electric field and b) magnetic field maximum values under 400kV double circuit conventional and compact lines for the symmetrical and the optimum arrangement as functions of lower conductor to ground distance h (considered currents 1000A, calculation height y = 1m).

Conventional line	Compact line	
———	— — —	Symmetrical arrangement
— - — - —	--------	Optimum arrangement

IV COMPACTION APPLICATION

A part of a new double circuit 400kV line in Switzerland, which crosses a high-populated area, was constructed with compact towers and composite insulated cross-arms due to space limitations, [5]. The compact tower of this line is shown in Figure 8b. In addition to the two 400kV circuits this line curries a 132kV (±66kV) single-phase circuit for the train supply. This line is an upgrade of ane xisting 125kV line, shown in Fig.8 a.T he optimum arrangement is used in both lines (125kV and 400kV). The height oft he compact towers has been mainly determined by the consideration, that the electric and magnetic field values at ground level should be approximately the same as for the existing 125kV line. This led to compact tower height of 56m.

Figure 9 shows the electric and magnetic field values under the 125kV linef or current I=500A, lower conductors to ground distance h = 10m, calculation height y = 1m and undert he 400kV line for I = 2000A, h = 30m and y = 1m. Thes ingle-phase circuit current is considered I = 500A. The influence of this circuit on the electric and magnetic field values at ground level is small. Figure 8 results show that the electric and magnetic field values under the 125kV line are similar to those produced by the 400kV line.

Figure 10 shows the electric and magnetic field maximum values undert he new 400kV line as functions of the lower conductor to ground distance h for thes ame calculation parameters as in Figure 9. The necessary lower conductor to ground distance h, so that them aximum electric and magnetic field values under the 400kV line do not exceed the maximum values under the 125kV one (as shown in Figure 9) is 27m for the optimum arrangement. If the symmetrical arrangement had been used this distance would be 57m and the total tower height83 m!

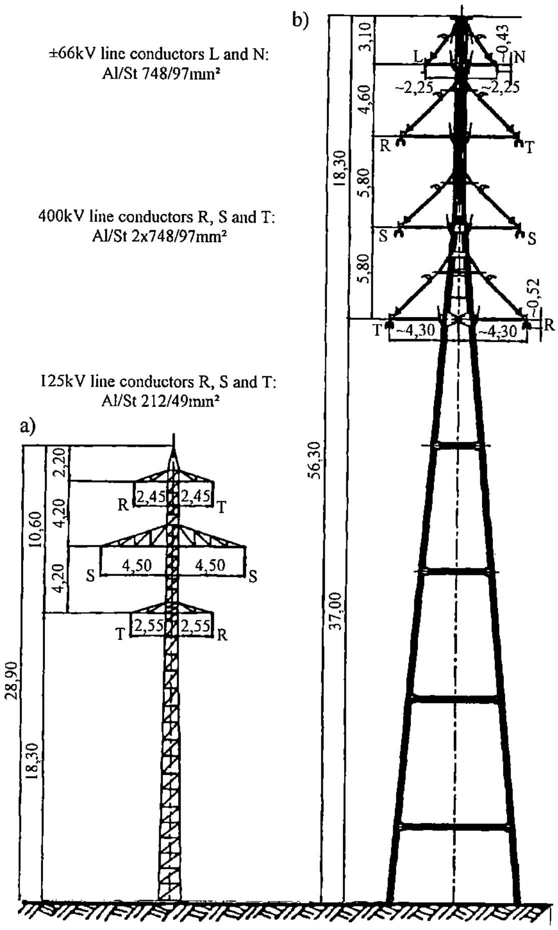

Fig.8 . a) existing 125kV line and b) constructed 400kV line tower.

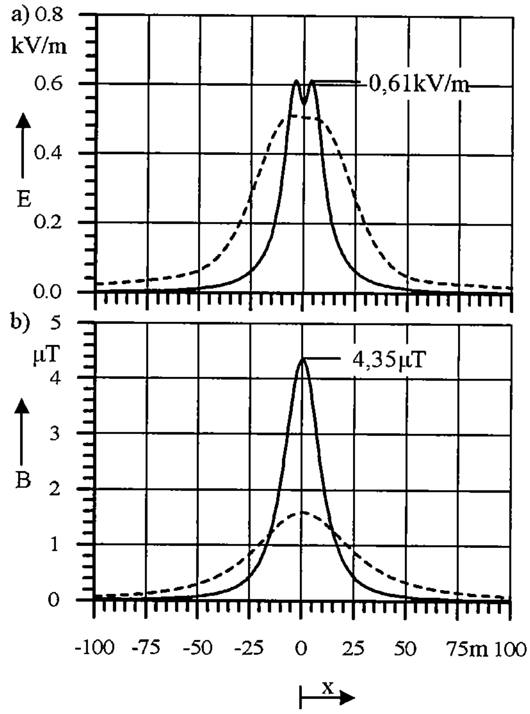

Fig. 9. a) Electric field and b) magnetic field values under the 125kV and the 400kV line as functions of the horizontal distance x from the line axis.

——— 125kV line -------- 400kV line

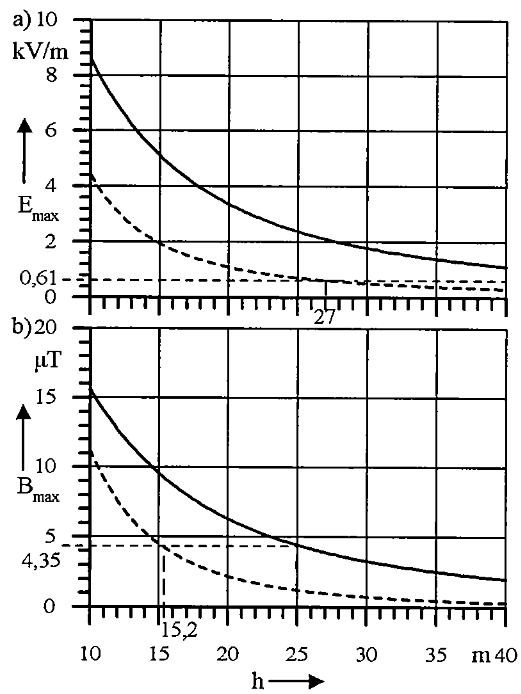

Fig. 10 a) Electric field and b) magnetic field maximum valuesu nder the 400kV compact line for the symmetrical and the optimum arrangement as functions of lower conductor to ground distance h.

——— Symmetrical arrangement
-------- Optimum arrangement

V CONCLUSIONS

Optimum phase arrangement application causes drastic reduction to electric and magnetic field values for both conventional and compact lines. This reduction is greater for compact lines than for conventional (not compacted) ones.

The electric and magnetic field measurement in the environment of a 400kV double circuit line, before and after thea pplication of the optimum phase arrangement, verified the drastic reduction of the field intensities. The application of this arrangement to an existing double circuit line is an easy process, achieved by proper interchanging of the phase conductors between the end tower and the substation.

Compaction in combination with the optimum phase arrangement of a double circuit line causes a great electric and magnetic field reduction. However, if the optimum phase arrangement is not used the field values produced by a compact line are similar to those produced by a conventionalo ne.

Compaction and optimum phase arrangement are also beneficial to two secondary metrics related to electric and magnetic fields: 1) The necessary ROW (Right of way) width so that the magnetic field values outside the ROW do not exceed given values and 2) the necessary tower height for E_{max} = 5kV/m (ICNIRPr eference level) are both drastically reduced due to the application of optimum arrangement. The reduction is again greater for the compact lines than for the conventionalo nes.

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VII BIOGRAPHIES

George Filippopoulos received hise lectrical engineering degree from the University ofP atras in Greece in 1996. He is ending his doctoral degree in the topic of three-phase power systemsm agnetic field analysis, supervised by professor Tsanakas at the same University. Since 2001 he is working at the Non Ionizing Radiation Office of the Greek Atomic Energy Committee. His scientific interests concern the analysis and measurement of the electric and magnetic fieldsp roduced by the electric power systems and the use of electricity in general.

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George Kouvarakis received the electrical and mechanical engineering degree from the National Technical University of Athens in 1971. From 1973 he is working at the Public Power Corporation in Greece on transmission projects. Since 2000 he is the Director of the Transmission Projects Department, responsible and for the environmental aspects of the transmission lines and substations.

John Voyatzakis received his electrical and mechanical engineering degree from the National Technical University of Athens in 1961. From 1964 he is working at the Public Power Corporation in Greece, on transmission projects. From 1991 to 1999 he was the Director of the Transmission Projects Department. Since 1999 he isa consulting engineer for transmission systems.

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Konstantin O. Papailiou received his electrical engineering degree from the Technical University of Braunschweig, his civil engineering degree from the University of Stuttgart and his doctoral degree from the Swiss Federal Institute of Technology (ETH) Zürich. He got engaged with transmission line work and high voltage engineering in 1975 as directoro f R+D and the Overseas Department of GEA in Fellbach, Germany. Since 1986 he isM anaging Director ofS EFAG AG in Malters, Switzerland. He is member of various working groups of CIGRE, IEC, CENELEC and SEV and has published several papers in this field.