Review of Structural Solutions in High-Voltage Overhead Power Lines and Possibilities of Reducing Emission of Electromagnetic Fields

Zbigniew Wróblewski, Dariusz Sztafrowski and Jacek Gumiela

Abstract This article compares the electromagnetic field distribution in the environment of overhead power lines built based on typical constructions of poles to be built as pipe–poles. On the basis of the distribution of digital simulation of the electric fields and magnetic fields specified range of the impact on the environment of overhead power lines. In conclusion, a proposed structure which the areas management under overhead power lines is optimal.

Keywords Electromagnetic fields · Digital simulations · Overhead power lines

1 Introduction

Power stations and power lines during their operation produce electromagnetic fields of 50 Hz, which can be considered as two separate components: electric and magnetic.

Electric fields occur due to the occurrence of the difference of potential, while magnetic fields are generated by the flowing current [1]. The electromagnetic field intensity achieved in the vicinity of high-voltage overhead power lines is mainly affected by the following parameters [1–4]:

- transmission line voltage,
- current intensity in phase wires,
- distance between phase wires and earth,
- distance between different phase wires or groups of wires, if the line uses bundle wires,

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– geometric arrangement of the phase wires and their mutual position cables or bundles of the same phase,
– area of wire cross section.

Identification of the distribution of electromagnetic fields around power lines can be performed using either the measurement method or calculation method [3, 5, 6]. Analytical methods commonly used for computational assessment of electromagnetic field intensity due to the applied simplification of the object or some of its electrical parameters yield results slightly different from the actual results [4]. In the case of numerical methods, obtaining an approximated result is a natural feature and calculations are finished after achieving the desired accuracy. A separate group consists of measuring methods which are subject to cumulative error of the measuring instrument and other errors resulting, among others, from irregularities of terrain, difficulty in identifying the perpendicular and rectilinear direction during the measurement process, and finally changes in the voltage and current during the measurement process [2, 3, 5].

The paper presents the results of digital simulation of the distribution of fields for several designs of single-circuit and double-circuit transmission lines installed on supporting truss or tube pylons. The obtained maximum values of electromagnetic fields generated under transmission lines and widths of technology strips for the example objects were compared.

2 Analysis of Distributions of Electromagnetic Fields Under High-Voltage Transmission Lines

Transmission of electricity over long distances is an integral part of modern civilization. The fact that electrical losses vastly depend on the transmission voltage, make it economically viable to construct higher voltage overhead lines. In practice, however, typical technical support structure solutions are commonly used for both single-circuit and multiple-circuit transmission systems.

At the design stage of every overhead transmission power line, it is necessary to specify the size of the exclusion zone and establishment of land easement in the whole zone. Then, to minimize the costs of purchase or lease of the land, it is important to accurately assess the impact of the line on the environment already at the stage of creating the technical–economic feasibility study and to ensure optimal management of land resources [5–7]. Such relatively simple measures usually yield significant cost savings [8] (Fig. 2).

While the power, voltage, and current are in this case predetermined, careful consideration of the spatial geometric arrangement of wires is highly recommended. This way, at low cost and through proper selection of supporting structures, the mutual positioning of the phase wires or the use of multi-lane systems [8–10] can help reduce the environmental impact of electromagnetic fields.

For the purpose of this study the author analyzed several variants of double-circuit transmission lines with rated voltages of 220 and 400 kV, installed on truss popular structures type M52, R220 in the case of the 220 kV line, and type Z52, E33P in the case of the 400 kV line (Fig. 4).

For double-circuit lines, an analysis of the distribution of electromagnetic field at both extremely favorable and extremely unfavorable positioning of phase wires was performed (Figs. 1 and 2), which produced significant differences in maximum intensity of electric and magnetic fields, as well as change of width of exclusion zone under the line [4, 8–10]. Numerical analysis of field distribution was performed using EMFields application to support simulation of complex multi-circuit and multi-voltage overhead transmission systems.

For comparison purposes, a number of general assumptions regarding the parameters of the analyzed power lines were adopted:

- rated voltage of the line $U = 220$ kV,
- full symmetry of voltages and currents,
- width of the zone for which the calculations were performed $X = /{-50}$ m from the axis of the line,
- calculation step delta $X = 0.2$ m,
- measuring height $h = 2.0$ m.

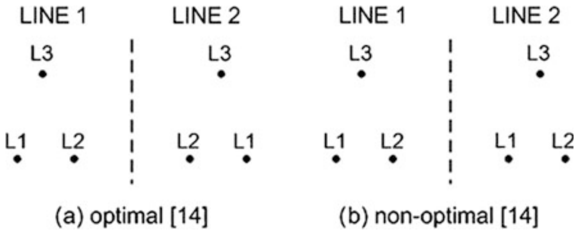


Fig. 1 Geometry of the phase wires for type M52 truss pylon

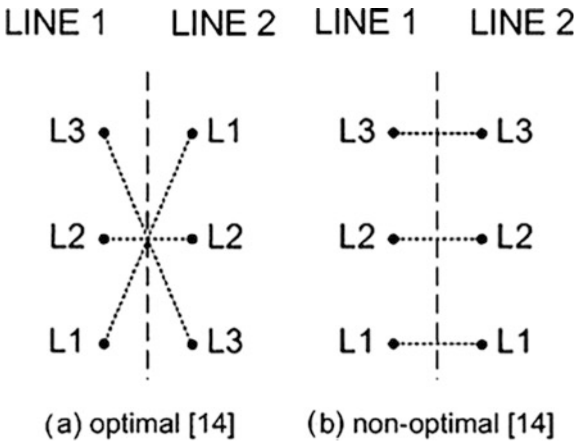
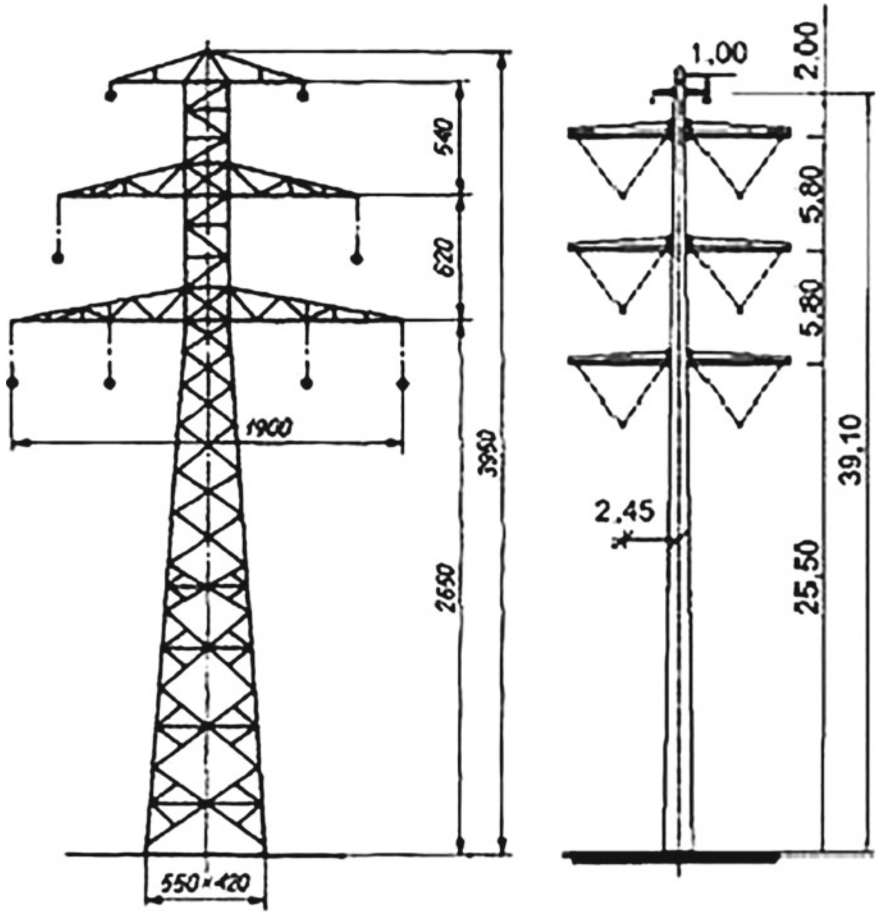


Fig. 2 Geometry of the phase wires for type R220, Z52, E33P pylon

2.1 Electromagnetic Field Under 220 kV Lines

Figure 3 shows the supporting structures, and Table 1 lists distances characterizing the arrangement of cables on truss pylons type M52 and R220 tubular type. The proposed geometric configuration of the double-circuit transmission line wires proves to be the most favorable in terms of the maximum intensity of the electromagnetic field [8]. For the purposes of determining the magnetic component of the field, it is assumed that the phase wires of the line carry operating currents of 600 A.



(a) pylon type M52 (b) pylon type R220

Fig. 3 Shapes of dual circuit 220 kV transmission line pylons. [*Source* http://www.elektroinstalacje.info]

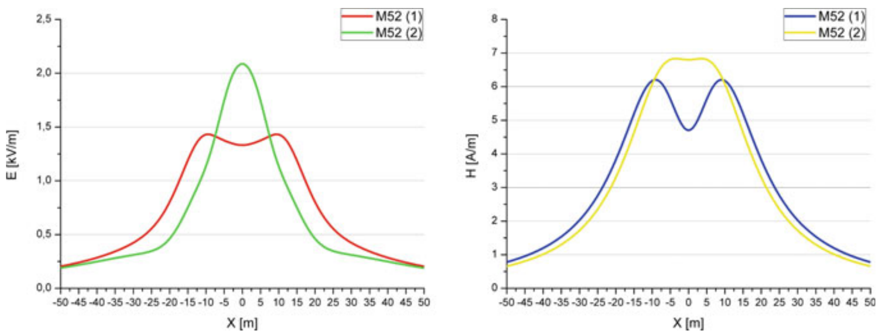
Table 1 Geometrical configuration of wires for the two-circuit 220 kV transmission line

	Pylon type M52 (truss)						Pylon type R220 (pipe)					
	LINE 1			LINE 2			LINE 1			LINE 2		
	L1	L2	L3	L1	L2	L3	L1	L2	L3	L1	L2	L3
X (m)	−4.9	−9.5	−7.2	9.5	4.9	7.2	−2.45			2.45		
Y (m)	13.0	13.0	19.2	13.0	13.0	19.2	12.0	17.8	23.6	23.6	17.8	12.0

A double-circuit overhead transmission line installed on the type M52 truss pylons generates an electric field with the maximum intensity about 46% smaller in the case of the optimal configuration of wires ($EM52_{(1)}$ = 1.43 kV/m against $EM52_{(2)}$ = 2.09 kV/m) (Fig. 4).

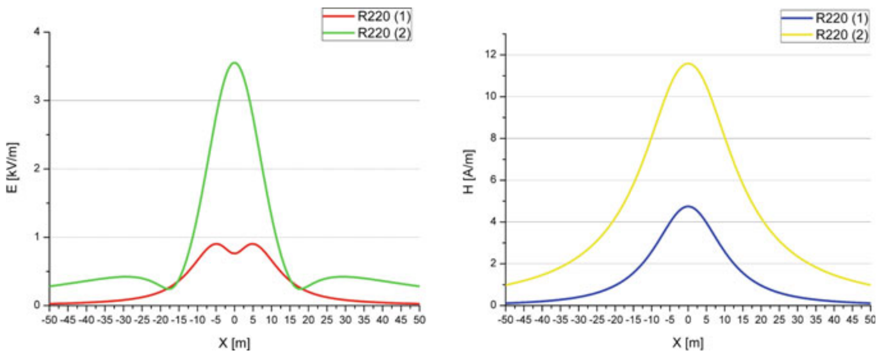
A double-circuit overhead line built on the M220 tube pylons generates an electric field with the maximum intensity about 300% smaller in the case of the optimal configuration of wires ($ER220_{(1)}$ = 0.90 kV/m against $ER220_{(2)}$ = 3.55 kV/m) (Fig. 5).

Smaller maximum intensity of both the electric component and a magnetic variant can be observed in R220 type pylons. It clearly shows that in the optimal configuration the electric field hardly reaches 1 kV/m (Fig. 5).



(a) electical component (b) magnetic component

Fig. 4 Electromagnetic field under 220 kV double-circuit transmission line installed on type M52 truss pylons



(a) electical component (b) magnetic component

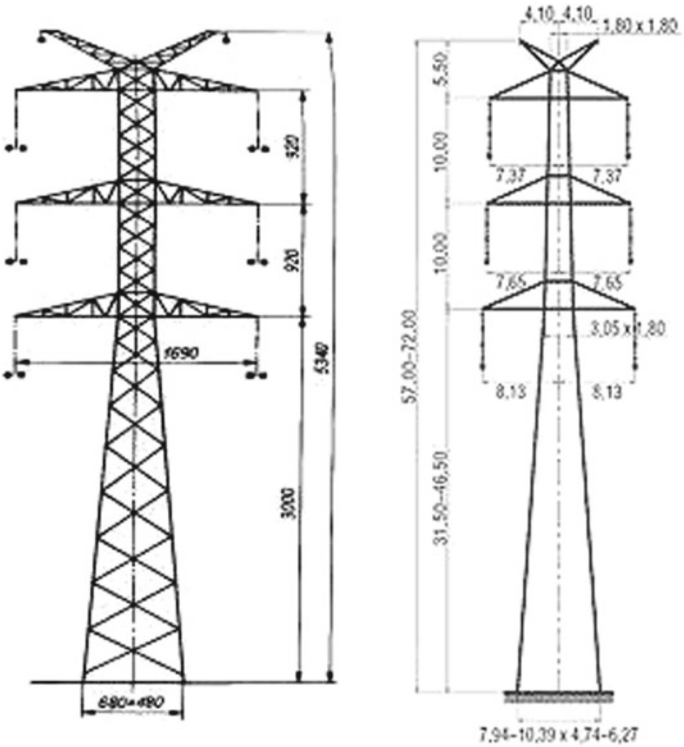
Fig. 5 Electromagnetic field under 220 kV double-circuit transmission line installed on type R220 pipe pylons

2.2 Electromagnetic Fields Under 400 kV Lines

Figure 6 shows the column structures, and Table 2 lists distances characterizing the arrangement of cables on straight-line support pylons type Z52 and E33P over-forest type. The proposed geometric configuration of the double-circuit line wires is the most favorable in terms of the maximum intensity of the electromagnetic field [8]. For the purposes of determining the magnetic component of the field, it is assumed that the phase wires of the line carry operating currents of 900 A.

Double-circuit overhead line built on the type Z52 truss pylons generates an electric field with a maximum intensity about 24% smaller in the case of the optimal configuration of wires ($EZ52_{(1)}$ = 3.226 kV/m against $EZ52_{(2)}$ = 4.010 kV/m) (Fig. 7).

Double-circuit overhead line built on the E33P over-forest pylons generates an electric field with a maximum intensity about 97% smaller in the case of the optimal configuration of wires ($EE33P_{(1)}$ = 1.542 kV/m against $EE33P_{(2)}$ = 3.045 kV/m) (Fig. 8).

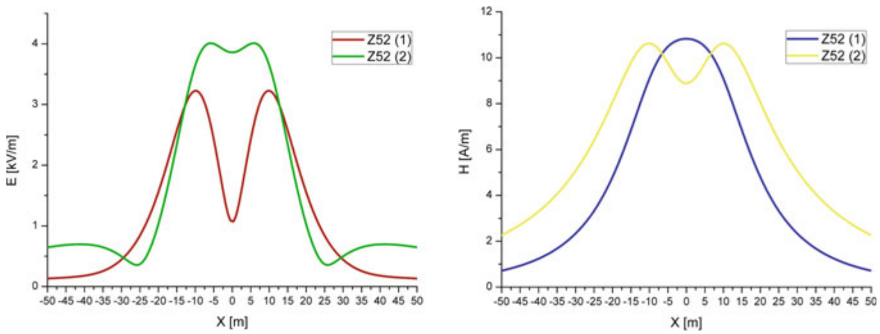


(a) pylon type Z52 (b) pylon type E33P

Fig. 6 Shapes of dual circuit 220 kV transmission line pylons. [*Source*: http://www.elektroinstalacje.info]

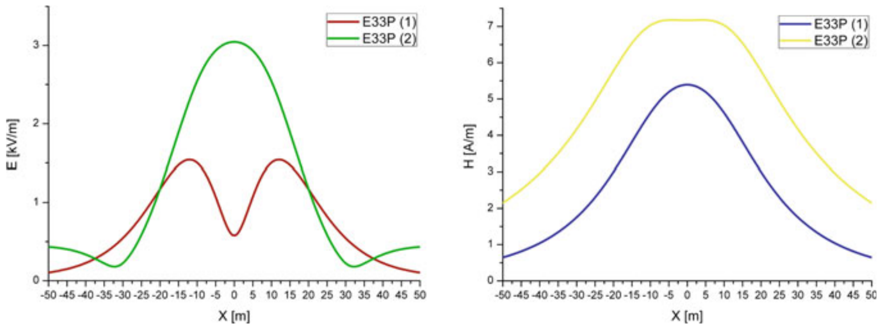
Table 2 Geometrical configuration of wires for the two-circuit 400 kV transmission line

	Pylon type Z52						Pylon type E33P					
	Line 1			Line 2			Line 1			Line 2		
	L1	L2	L3	L1	L2	L3	L1	L2	L3	L1	L2	L3
X (m)	−8.45			8.45			−8.13	−7.65	−7.37	7.37	7.65	8.13
Y (m)	32.4	23.2	14.0	14.0	23.2	32.4	20.5	30.5	40.5	40.5	30.5	20.5



(a) electical component (b) magnetic component

Fig. 7 Electromagnetic field under 400 kV double-circuit transmission line installed on type Z52 truss pylons



(a) electical component (b) magnetic component

Fig. 8 Electromagnetic field under 400 kV double-circuit transmission line installed on type E33P pylons

Smaller maximum intensity of both the electric and magnetic components can be observed in the variant with E33P type pylons.

In addition, for both examined 400 kV pylons the electric component of the field decreases with distance from the axis of the line, and then, at a distance of several meters, there is a slight increase in the value of electric field intensity to a local maximum, beyond which it again reduces its value with the distance from the power line (Figs. 7 and 8).

2.3 Summary of Results

Tables 3 and 4 present results of the digital simulation conducted to analyze the electromagnetic field distribution in the space underneath the line wires.

Table 3 Comparison of maximum intensity of electric and magnetic fields and the width of the exclusion zone below the line in which the field intensity is exceeded

Dual circuit 220 kV transmission line				
Construction	E (kV/m)	$d_{E>1\ kV/m}$ (m)	H (A/m)	$d_{H>60\ A/m}$ (m)
R220 (O)	0.90	–	6.21	–
R220 (N)	3.55	−11.2 to +11.2	6.84	–
M52 (O)	1.43	−17.2 to +17.2	4.74	–
M52 (N)	2.09	−11.6 to +11.6	11.59	–

Table 4 Comparison of maximum intensity of electric and magnetic fields and the width of the exclusion zone below the line in which the field intensity is exceeded

Dual circuit 400 kV transmission line				
Construction	E (kV/m)	$d_{E>1\ kV/m}$ [m]	H (A/m)	$d_{H>60\ A/m}$ (m)
E33P (O)	1.542	−22.2 to +22.2	5.394	–
E33P (N)	3.045	−21.2 to +21.2	7.181	–
Z52 (O)	3.226	−23.6 to +23.6	10.829	–
Z52 (N)	4.010	−20.0 to +20.0	10.624	–

It is worth noting that all the examined varieties of double-circuit lines share a common relationship that lower maximum electric field intensity comes at the expense of wider zone in which it may exceed the maximum permissible value of 1 kV/m [11]. The magnetic component does not exceed the limit of 60 A/m in any of the measurement points [11]. Electric power lines are the source of electromagnetic field which, for safety reasons, should not exceed the values set out in relevant legislation [11–13].

In the design phase of new infrastructure these objects are located far from human settlements. However, there is often intensive development near existing overhead power lines. The impact zone designed according to the old criteria that are not in effect today may no longer meet the current permissible values of electric field intensity at various locations inhabited by people [13, 14]. Reconstruction of the power line in order to remove the conflict is, for many reasons, not always feasible. Such alteration may also be very expensive.

Multiple-circuit lines, with a particular arrangement of electrical circuits, demonstrate the effect of field compensation and consequently, the resultant electric field generated by two electrical circuits may be lower than the electric field generated individually by either of these circuits.

3 Conclusions

1. Specialized support structures, through the use of a different geometry, allow reducing electromagnetic fields generated in the vicinity of high-voltage lines.
2. In the case of double-circuit lines, the geometric configuration of cables is especially important, as in extreme cases, the intensity of electromagnetic fields generated by wires can be reduced several times due to compensation of the influence of individual wires or entire electric circuit.
3. It is possible to achieve the effect of reducing the maximum intensity of the electromagnetic field without changing the transmission capacity of the overhead line or reduce the width of the exclusion zone exposed to certain intensity through the appropriate spatial arrangement of cables on the supporting structures.
4. When designing an overhead multi-circuit power line typically a choice must be made about one of the available solutions to strike the right balance between the maximum value of the intensity of the electromagnetic field and the width of the strip of land where the electromagnetic field strength decreases relatively slowly with the distance from the axis of the line.

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