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Regulations for protection against electric and magnetic fields and optimum solution for the development of 150kV transmission lines in suburban regions

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Abstract: Initially the regulations for protection against electric and magnetic fields are presented. Their scientific documentation is described, which is based on the evaluation of all relative scientific publications. Afterwards, nine alternative solutions of overhead transmission lines and underground cables for the development of 150kV grids in suburban regions are examined. As optimum solution for the minimization of the magnetic field results the overhead double-circuit compact line with the optimum arrangement of the phase conductors. This also is the optimum solution as long as it concerns the electric field of overhead transmission lines. As optimum solution for transmission with underground cables, results the triangular arrangement of three single-core cables in contact to each other.

Key-Words: electric field, magnetic field, power lines, compact lines, cables, symmetrical arrangement, optimum arrangement

1 Introduction

The electric and magnetic fields of power lines, substations and electric appliances are considered as environmental factors. The determination of exposure limits is very important in order to provide protection to general public and workers.

In chapter 2 guidelines and regulations for the public protection are presented (Guidelines of the International Commission on Non-Ionizing Radiation Protection ICNIRP, guidelines of the European Union, national regulations). In this chapter the process of the limits determination and their scientific documentation, is also described.

In chapter 3 nine alternative solutions for the development of 150kV grids are described (seven solutions of overhead transmission lines and two solutions of underground cables). These solutions were examined for the same transmission capability and constitute technically genuine alternative solutions. In chapter 3, the results of calculations for the classification of overhead lines and cables according to the fields, are also given.

2. Regulations for protection against electric and magnetic fields

2.1 Limit values of the field intensities

Table 1 contains the limit values (reference values) of the field intensities for the general public and occupational exposure in 50Hz fields, which are given in various guidelines and regulations:

The International Radiation Protection Association (IRPA) in 1977 established the International Non-Ionizing Radiation Committee (INIRC). This Committee, in cooperation with the Environmental Health Division of the World Health Organisation (WHO), published in 1990 the interim guidelines on limits of exposure [1a]. In this publication, all the relative scientific publications had been examined.

In 1997 the guidelines of the International Committee on Non-Ionizing Radiation Protection (ICNIRP) on the limits of exposure to time-varying electric, magnetic and electromagnetic fields, were completed [1b]. ICNIRP established as a successor to IRPA/INIRC. For the development of these guidelines all the newer relative scientific works had been examined. In these guidelines, without the restriction "interim guidelines", the limit values

5kV/m and 100μT for the general public exposure and 10kV/m and 500μT for the occupational exposure, remain the same as in [1a].

In 1993, the British regulation [2a] was published with considerably higher limit values against the limit values of ICNIRP. However, with the publication [2b] in 2004, the limits of ICNIRP were adopted.

In 1996 the German federal decree [3] was published, in which the limit values for the general public exposure in electric and magnetic fields are enacted. These limit values coincide with the limit values of guidelines [1b].

In 1999 the recommendation of the European Union Council on the limitation of exposure of the general public to electromagnetic fields [4] was published. In this recommendation, the Council adopted the limit values of the ICNIRP guidelines after their ratification from the Scientific Coordinative Committee of the European Committee.

In 2002 in Greece, the Ministerial Decision (Act No. 512/Vol.B/25-04-2002) was published, in which the limit values of the European Committee [4] are adopted.

In 2004, the Directive of the European Parliament and Council [5] was published, in which the limit values of ICNIRP for the occupational exposure are adopted.

Limit values / Protection regulations	Region			
	Public exposure		Occupational exposure	
	E kV/m	B μT	E kV/m	B μT
Interim guidelines IRPA/INIRC, 1990, [1a] / Guidelines ICNIRP, 1998, [1b]	5	100	10	500
British regulation NRPB,1993,[2a]	12	1600	12	1600
Review NRPB, 2004, [2b]	5	100	10	500
German federal decree 26.BIMSchV 1996, [3]	5	100	-	-
Recommendation of the European Union Council, 1999, [4]	5	100	-	-
Directive of the European Parliament and Council for the occupational exposure, 2004, [5]	-	-	10	500

Table 1: Limit values of the field intensities for the general public and occupational protection against electric and magnetic fields of 50Hz frequency.

The limit values of the electric and magnetic fields in the regulations are not risk limits, but they include very big safety factors, so that the ambiguities from the limited knowledge of the fields' effect are covered and the requirement for prevention of health hazards is fulfilled.

2.2 Scientific basis of the limit values

Fig.1 shows the numbers of the registered publications in scientific journals, which concern the effects of the electric, magnetic and electromagnetic fields in health per year till 02.04.2006, in the bibliographic base of data of Research Center for Bioelectromagnetic Interaction, FEMU, [6].

From Fig.1 results the large increase rate of the number of the relative publications with the by-way of years and the big number of publications. These publications are reported mainly on medical, biological, technical and epidemiological issues.

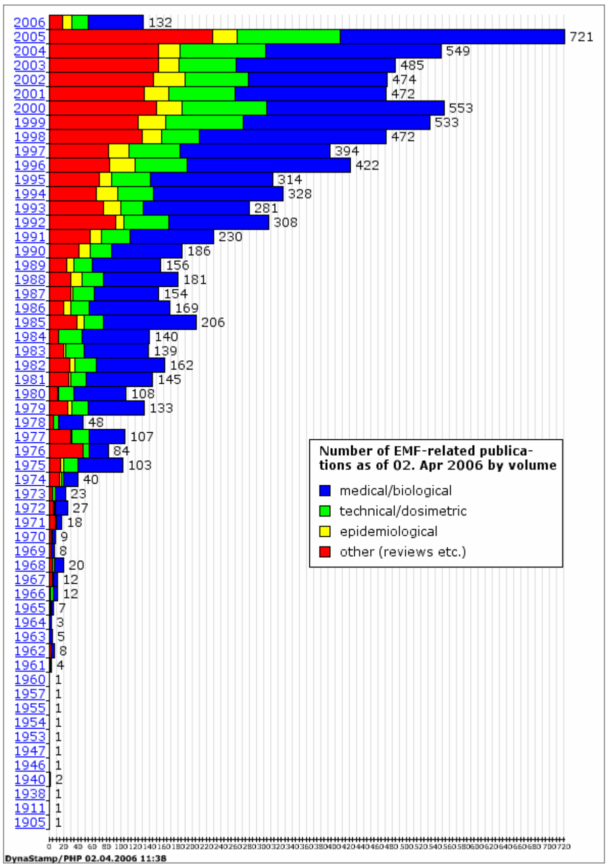

Fig.1. Numbers of registered publications in scientific journals, which concern the effect of electric, magnetic and electromagnetic fields in health per year, till 02.04.2006

The limit values of the field intensities for the health protection should be based on ensured scientific knowledge. These values should not be influenced by economical and political criteria. The limit values result from the critical examination of all relative scientific publications from organizations with inter-scientific composition, such as ICNIRP, according to qualitative criteria [7]. ICNIRP is an independent non-governmental organization for the protection against electromagnetic fields and is recognized by the World Health Organization, the European Union and the International Labour Office. ICNIRP proceeds in the examination of all newer scientific works. The last review, which is included in book [8], didn't result in a change of the limit values.

3 Optimum solution for the development of 150 kV grids

3.1 Examined arrangements

Nine alternative solutions for the development of 150kV grids in suburban and urban regions are examined. Fig.2 to 4 show these nine alternative solutions, three arrangements of single circuit overhead lines (Fig.2), four arrangements of double circuit overhead lines (Fig.3), and two arrangements of underground cables (Fig.4). More analytically:

Fig.2 shows:

- One single circuit conventional line, (Fig.2a)
- Two single circuit compact lines, one with vertical arrangement, (Fig.2b) and one with triangular arrangement, (Fig.2c).

Fig.3 shows:

- Two double circuit conventional lines, one with the symmetrical arrangement of phase conductors (BAC/BAC), (Fig.3a) and one with the optimum arrangement of phase conductors (BAC/CAB), (Fig.3b)
- Two double circuit compact lines, one with the symmetrical arrangement (BAC/BAC), (Fig.3c) and one with the optimum arrangement (BAC/CAB), (Fig.3d).

The optimum arrangement of phase conductors for double circuit lines and the reduction of the field intensities, are presented in [9] and [10].

Fig.4 shows:

- Three single-core cables in horizontal arrangement, (Fig.4a),
- Three single-core cables in triangular arrangement in contact to each other, (Fig.4b).

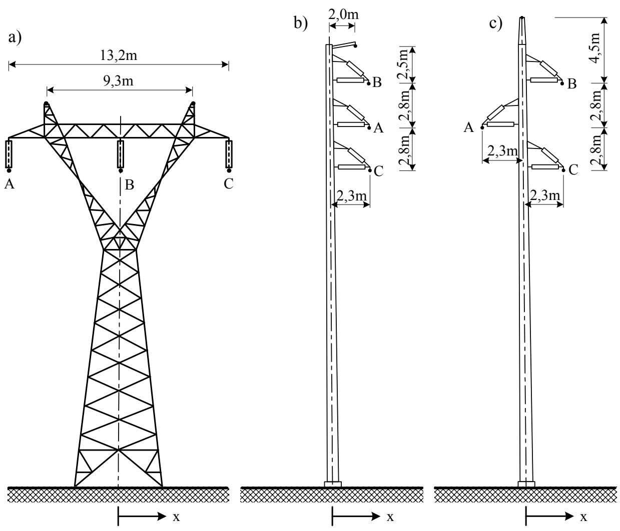

Fig.2. Arrangements of 150kV single circuit lines.
a) Conventional line
b) Vertical compact line
c) Triangular compact line

All the alternative solutions were examined for the same transmission power of 130MVA (500A per phase in 150kV). The results of magnetic flux density for the above currents can be converted to different currents, because magnetic flux density is proportional to the current. For this reason the classification of all alternative solutions based on field intensities, does not change for each transmitted power.

The maximum values of the intensity of the electric field E_{max} and the magnetic flux density B_{max} are calculated:

- For the overhead lines the magnetic flux density is calculated for height 2m from ground, with distance between the lower conductors and the ground 10,5m.
- For the underground cables the magnetic flux density is calculated for height 0,5m above ground and the cables are installed in 1,4m depth.

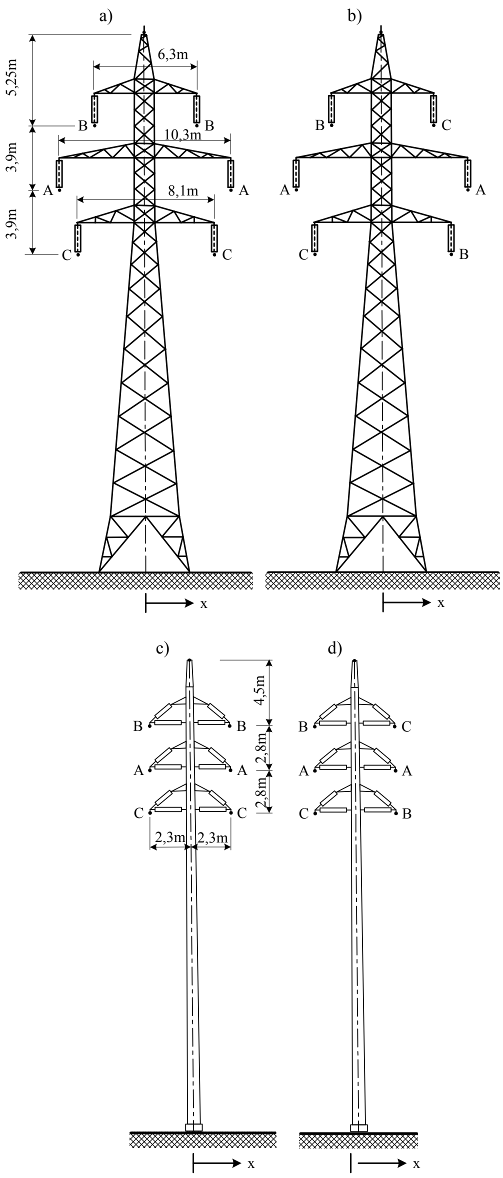

Fig.3. Arrangements of 150kV double circuit lines.
a) Conventional line with the symmetrical arrangement of phase conductors
b) Conventional line with the optimum arrangement of phase conductors
c) Compact line with the symmetrical arrangement
d) Compact line with the optimum arrangement

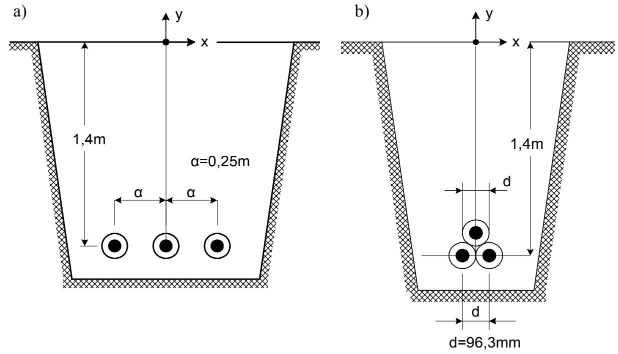

Fig.4. Underground cables arrangements.
a) Cables in horizontal arrangement
b) Cables in triangular arrangement in contact to each other

3.2 Calculation results

Fig.5 shows the field intensities for all the alternative solutions in order to be capable the comparison of these solutions. Fig.5a shows the intensity of the electric field and Fig.5b shows the magnetic flux density.

The numbers of curves in Fig.5 represent the nine alternative solutions as follows:
- Curve 1, the single circuit conventional line, (Fig.2a).
- Curve 2, the single circuit compact line with vertical arrangement of the conductors, (Fig.2b).
- Curve 3, the single circuit compact line with triangular arrangement of the conductors, (Fig.2c).
- Curve 4, the double circuit conventional line with the symmetrical arrangement (BAC/BAC), (Fig.3a).
- Curve 5, the double circuit conventional line with the optimum arrangement (BAC/CAB), (Fig.3b).
- Curve 6, the double circuit compact line with the symmetrical arrangement (BAC/BAC), (Fig.3c).
- Curve 7, the double circuit compact line with the optimum arrangement (BAC/CAB), (Fig.3d).
- Curve 8, the three single-core cables in horizontal arrangement, (Fig. 4a).
- Curve 9, the three single-core cables in triangular arrangement in contact to each other, (Fig.4b).

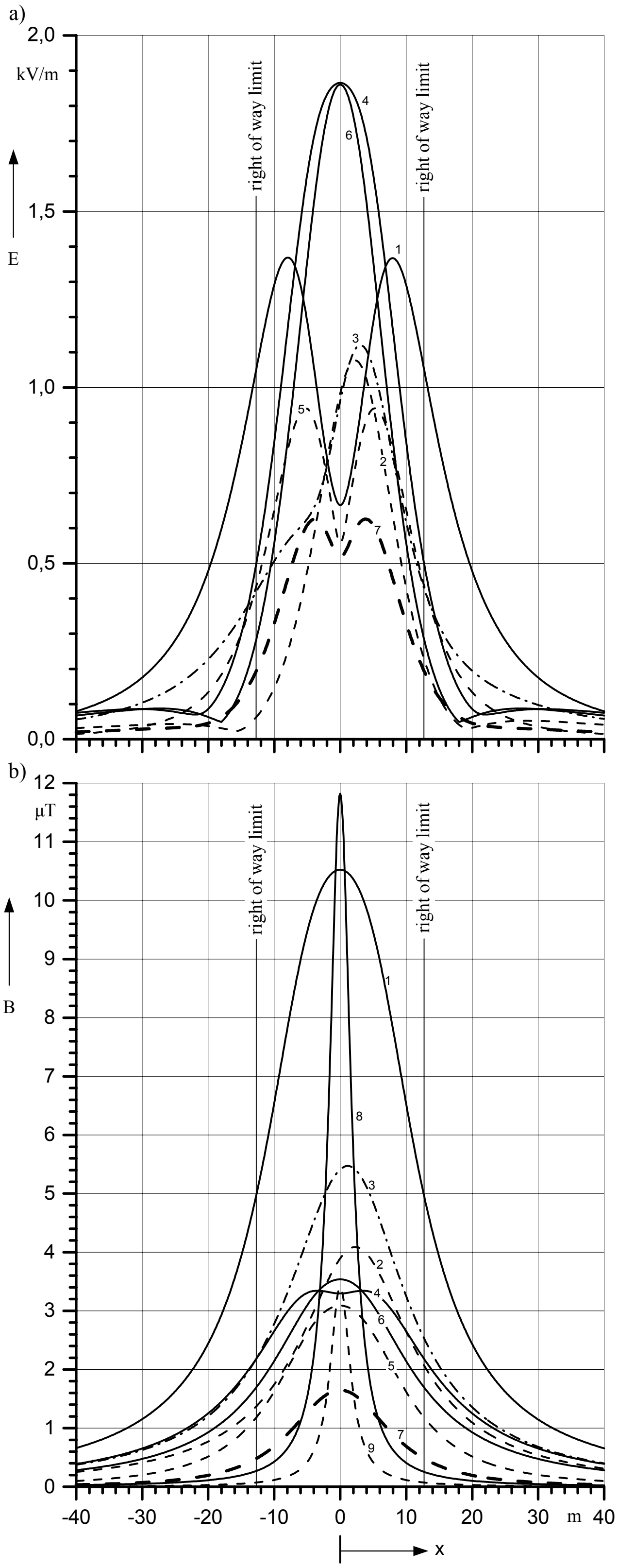

Fig.5. a) Intensity of the electric field and b) Magnetic flux density for transmission of 130MVA by 150kV lines and cables. Calculations height from ground for the overhead lines 2m and for cables 0,5m.

Fig.5b and table 2 show the drastic limitation of magnetic flux density with the use of double circuit compact line, which has the optimum arrangement of phase conductors, in comparison with all the other solutions including the two underground solutions. Fig.5b and table 2 show that this arrangement causes also the most drastic limitation of the intensity of the electric field of all the overhead lines solutions.

No	Alternative solutions	fig.	E_{max} kV/m	$\frac{E_{lim}}{E_{max}}$	B_{max} μT	$\frac{B_{lim}}{B_{max}}$
1	Single circuit conventional line	1a	1,37	3,6	10,52	9,5
2	Single circuit compact line with vertical arrangement of the conductors	1b	1,08	4,6	4,09	24,4
3	Single circuit compact line with triangular arrangement of the conductors	1c	1,12	4,5	5,47	18,3
4	Double circuit conventional line with the symmetrical arrangement of the phase conductors (BAC/BAC)	2a	1,87	2,7	3,34	29,9
5	Double circuit conventional line with the optimum arrangement of the phase conductors (BAC/CAB)	2b	0,94	5,3	3,09	32,4
6	Double circuit compact line with the symmetrical arrangement of the phase conductors (BAC/BAC)	2c	1,86	2,7	3,54	28,2
7	Double circuit compact line with the optimum arrangement of the phase conductors (BAC/CAB)	2d	**0,63**	7,9	**1,65**	60,6
8	Three single-core cables in horizontal arrangement	3a	-	-	11,82	8,5
9	Three single-core cables in triangular arrangement in contact to each other	3b	-	-	3,41	29,3

Table 2. Typical values of the intensity of the electric field and the magnetic flux density for all the alternative arrangements.
E_{max}: Maximum value of the intensity of the electric field
E_{lim}=5 kV/m: Limit value of the intensity of the electric field
B_{max}: Maximum value of the magnetic flux density
B_{lim}=100μT: Limit value of the magnetic flux density

The intensity of the electric field, which is produced in the vicinity of underground cables, is zero, because of the electric shielding of the cables. The effort of minimization of magnetic flux density for the transmission with underground cables leads to the solution of three single-core cables in triangular arrangement in contact to each other. This arrangement produces for the magnetic flux density, maximum value 3,41μT. This maximum value is twice the corresponding maximum value of 1,65μT of the double circuit compact line with the optimum phase arrangement. Respectively, the three single-core cables in horizontal arrangement produce maximum value of magnetic flux density 11,82μT (value 7 times bigger than the 1,65μT of the double circuit compact line with the optimum phase arrangement).

The triangular arrangement of cables in contact to each other, not only produces reduced magnetic flux density related to the horizontal arrangement of cables, but also has economical benefits [11,12]. The transmission capability of the cables with triangular arrangement is reduced about 12% against the horizontal arrangement. The reduction of the transmission capability can be faced with the cross-section increase of cables, which causes cost increase. However, this increase is less than the cost saving, which is achieved by the restriction of ditch and the absence of cross bonding materials.

4 Conclusions

The basic conclusions are the following:

- ICNIRP's guidelines for the general public protection against electric and magnetic fields are based on the examination of all relative scientific publications.
- Single circuit compact lines produce smaller maximum values of the electric and magnetic fields against the conventional power lines.
- Double circuit compact lines do not cause reduction of the maximum values of the electric and magnetic fields in relation with conventional power lines when the symmetrical arrangement of the phase conductors is used.
- The electric and magnetic fields of double circuit power lines have smaller values, when the optimum arrangement of the phase conductors is used.
- The use of double circuit compact lines with the optimum arrangement of the phase conductors causes drastic reduction of the maximum values of the electric and magnetic field against all the other solutions of single circuit and double circuit power lines.
- Transmission with underground cables, causes zero values of the electric field in the vicinity of cables. The maximum values of the magnetic flux density in the vicinity of cables, in positions accessible to the general public, remain higher from the corresponding values in the vicinity of double circuit compact lines as long as the optimum arrangement of the phase conductors is used. This is also in effect when the cables are placed in triangular arrangement in contact to each other (minimization of magnetic field).

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