CONSTRUCTIONAL MAGNETIC FIELD REDUCING MEASURES OF HIGH VOLTAGE OVERHEAD TRANSMISSION LINES

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ABSTRACT

The technical and environmental demands for reducing magnetic and electric fields of high voltage transmission lines are a focal point of science and development since a long time. In this paper optimisation measures and problems occurring in the course of reducing magnetic fields of two or three phase overhead transmission lines will be discussed and presented.

INTRODUCTION

The construction of overhead transmission line towers depends on technical standards dealing with mechanical design and safety on the one hand. On the other hand environmental effects and influences on humans have to be observed.

Constructional parameters like distances of phases to each other and to the ground, as well as electrical parameters such as magnitude and phase positions of current and voltage lead to different disturbing effects on the environment. Generally these environmental effects can be described directly or indirectly by magnetic and electric fields, radio interference, as well as with noise. Designing a new type of tower all these effects have to be considered and reduced to a minimum.

The increasing sensitivity of people related to the effects of magnetic and electric fields on humans are the basis of efforts to reduce the environmental effects by changing constructional parameters of power lines. These results are compared with the characteristics of conventional tower constructions in this paper.

The principle options for reducing magnetic and electric fields of power lines are:

- reduction of the voltage level and/or load current,
- increasing of the distance to the field sources,
- electric field shielding: conductive sheet materials, shielding conductor
- magnetic field shielding: compensation conductor, overhead earth wire compensation, magnetic shielding foil, …

The goal of this paper is to show the development of optimal geometric conductor positions, phase arrangements and shielding/compensation conductor arrangements, in order to shield and/or reduce the magnetic field as good as possible.
The effects of symmetrical and crossed phase arrangements and the resulting influence of an overhead earth wire on the near and/or far magnetic field, as well as the influence of an additional shielding and compensation conductor as a function of distance are analysed in the following.

METHOD OF CALCULATION

The computation of magnetic flux density is based on the theory of Biot & Savart as a two-dimensional vertical model (without ground influence, without influence of neighbouring magnetically effective materials).

The calculation is done in two steps:

1. Calculation of conductor's currents, active phases and field-reducing conductors (Carson & Pollaczek) [1]

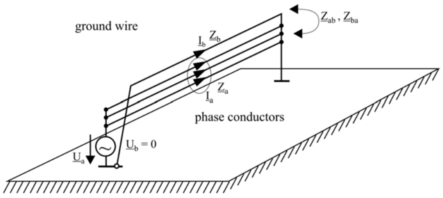

Figure 1: Interference model

Using equ. (1)

$$\begin{pmatrix} \underline{U}_a \\ 0 \end{pmatrix} = \begin{pmatrix} \underline{Z}_{aa} & \underline{Z}_{ab} \\ \underline{Z}_{ab} & \underline{Z}_{bb} \end{pmatrix} \cdot \begin{pmatrix} \underline{I}_a \\ \underline{I}_b \end{pmatrix} \qquad (1)$$

$\underline{U}_a$	voltage of active phase conductors
$\underline{U}_b$	voltage of earth conductors, $\underline{U}_b = 0$
$\underline{Z}_{aa}$, $\underline{Z}_{bb}$	impedances
$\underline{Z}_{ab} = \underline{Z}_{ba}$	mutual impedances, systems a, b

the resulting currents $\underline{I}_b$ of the earth wire b can be calculated as follows:

$$\underline{I}_b = -\underline{Z}_{bb}^{-1} \cdot \underline{Z}_{ab} \cdot \underline{I}_a \qquad (2)$$

The phase currents $\underline{I}_a$ and the currents of the earth wires cause together the magnetic emissions of the overhead power line.

2. Calculation of magnetic field (Biot & Savart) [2]

It is important, that a complete description of the magnetic and electric field in a space reference point is not possibly by one single value, the direction must be considered too. Stationary and quasi-stationary magnetic fields (as the magnetic field of the earth, e.g. 50 Hz fields) and electric fields (atmospheric electric fields) have constant field intensity and a constant direction in the space. They can be described by a vector field. Usually the vector components can be modeled using three functions of the reference point coordinates (x-, y- and z-direction). For time changeable magnetic fields (transmission lines) time is another determinant parameter. Each of the three space components B_x, B_y and B_z have a time changing course. Equ. 3 describes the magnetic flux density $\vec{B}$ [1] in a space reference point A (Figure 2)

$$\vec{B}(x,y,z,t) = \begin{pmatrix} B_x(x,y,z,t) \\ B_y(x,y,z,t) \\ B_z(x,y,z,t) \end{pmatrix} \tag{3}$$

The resulting field of a complex group of conductors can be calculated using Biot & Savart´s law and summing up the contribution of each single piece of conductor to the field in a space reference point as detailed showed in [3].

$$d\vec{B} = \frac{\mu_0 \cdot I}{4 \cdot \pi} \cdot \frac{d\vec{\xi} \times \vec{r}_{QA}}{\left|\vec{r}_{QA}\right|^3} \tag{4}$$

$d\vec{\xi}$	path increment in direction of current
$\vec{r}_{QA}$	radius from source to reference point A(x,y,z)
I	Current

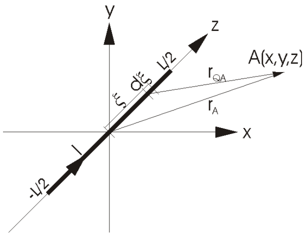

Figure 2: Single conducting line element

$$\vec{r}_A = x \cdot \vec{e}_x + y \cdot \vec{e}_y + z \cdot \vec{e}_z \tag{5}$$

$$\vec{r}_Q = \xi \cdot \vec{e}_z \tag{6}$$

After integration over the x- and the y-component of the magnetic flux density can by calculated in any spatial point A(x,y,z).

$$B(x,y,z) = \frac{\mu_0 \cdot I}{4 \cdot \pi} \cdot \int_{\xi=-l/2}^{\xi=l/2} \frac{\left(-y \cdot \vec{e}_x + x \cdot \vec{e}_y\right) \cdot d\xi}{\left(x^2 + y^2 + (z-\xi)^2\right)^{3/2}} \tag{7}$$

$$B_x = \frac{\mu_0 \cdot I}{4 \cdot \pi} \cdot \frac{y}{\left(x^2+y^2\right)} \cdot \left(\frac{(z-l/2)}{\sqrt{x^2+y^2+(z-l/2)^2}} - \frac{(z+l/2)}{\sqrt{x^2+y^2+(z+l/2)^2}} \right) \tag{8}$$

$$B_y = -\frac{\mu_0 \cdot I}{4 \cdot \pi} \cdot \frac{x}{\left(x^2+y^2\right)} \cdot \left(\frac{(z-l/2)}{\sqrt{x^2+y^2+(z-l/2)^2}} - \frac{(z+l/2)}{\sqrt{x^2+y^2+(z+l/2)^2}} \right) \tag{9}$$

$$B_z = 0 \tag{10}$$

x; y; z; l	length in m
I	inducing current in A

Furthermore, in context with the evaluation of magnetic fields, following the pre-standard ÖVE/ÖNORM E 8850 [4] (similar to ICNIRP), for elliptical rotary fields the equivalent magnetic flux density B_{EFD} can be calculated in the following way:

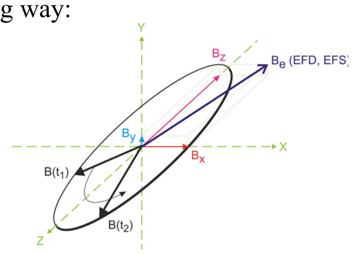

Figure 3: Equivalent magnetic flux density

$$B_{EFD} = \sqrt{B_x{}^2 + B_y{}^2 + B_z{}^2} \tag{11}$$

This equivalent magnetic flux density can be measured easily and is a safe measure neglecting phase informations.

ANALYZED HEADS OF TOWERS

The following investigations considering different types of double circuit lines for two and three phase systems of standard 110 kV overhead transmissions lines as used in Austria. Furthermore the dimensions of tower heads were varied down to the smallest possible dimensions (least distance of the conductors, least possible tower height) for two and three phase systems considering the actual Austrian respectively European standard ÖVE/ÖNORM EN 50341 [5] as a safety limit. These fictitious assumptions were analyzed and compared to the standard tower heads.

In order to compare the magnetic emissions caused by the conductors of the different tower profiles, the computations of the magnetic flux density were done in the following at the lowest point of the line section with a distance to ground from 6 m to the lowest wire. Furthermore for all tower types the some conductor cross sections were assumed (both for the phase conductors L1 … L3' and the overhead earth wire E).

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[1] [B] = 1 T (Tesla)

The tower dimensions are classified as follows:

I	standard tower (3~, 50 Hz, 110 kV)
II	fictitious compact tower (3~, 50 Hz, 110 kV)
III	standard tower (2~, 16,7 Hz, 110 kV)
IV	fictitious compact tower (2~, 16,7 Hz, 110 kV)

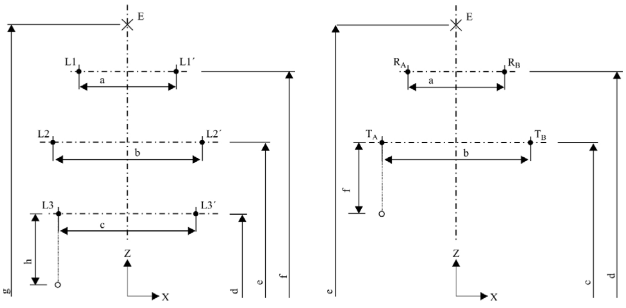

Figure 4: Phase configuration: left: (I,II), right: (III,IV)

		a	b	c	d	e	f	g	h
I	distance in m	6	9	7,5	11	16	21	26	5
II		2,3	5,22	3,76	11	13,18	14,95	16,95	5

		a	b	c	d	e	f
III	distance in m	6,2	7,7	11	17	23,8	5
IV		2,3	4,1	11	13,2	15,2	5

Table 1: Distances for phase configuration

RESULTS

The direct comparison of the calculation[2] results with different conductor configurations offers, that it is difficult to decide which conductor configuration results in smaller magnetic field. The diagram in Figure 5 (in summary in the table 2/I) shows the field +/- 30 m of the center of the overhead line in 3 different heights (0 m, 1 m and 2 m above ground). While the phase configuration A (Table 1, Figure 4) produces a lower field in 0 m above ground compared with phase configuration B the phase configuration B produces a lower field in 1 m and 2 m above ground compared with phase configuration A.

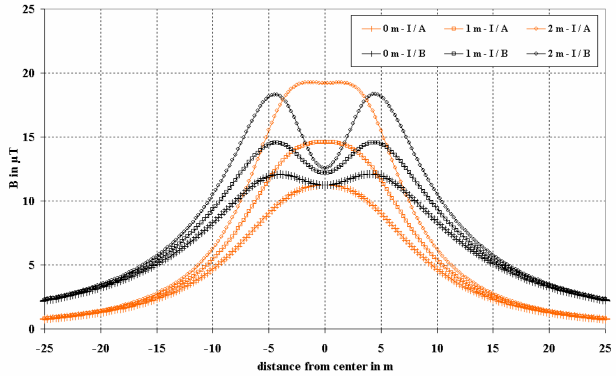

Figure 5: Magnetic flux density in horizontal direction

	I						**Magnetic Field**						
							x m from center / z m above ground				max(z m above ground)		
	phase configuration						-100 m / 0 m	-100 m / 1 m	-100 m / 2 m		max(0 m)	max(1 m)	max(2 m)
	L1	**L2**	**L3**	**L1´**	**L2´**	**L3´**	µT	µT	µT		µT	µT	µT
A	0°	120°	240°	240°	120°	0°	0,037	0,037	0,037		11,259	14,616	19,248
B	0°	120°	240°	120°	0°	240°	0,181	0,181	0,180		12,109	14,571	18,355

	II						**Magnetic Field**						
							x m from center / z m above ground				max(z m above ground)		
	phase configuration						-100 m / 0 m	-100 m / 1 m	-100 m / 2 m		max(0 m)	max(1 m)	max(2 m)
	L1	**L2**	**L3**	**L1´**	**L2´**	**L3´**	µT	µT	µT		µT	µT	µT
A	0°	120°	240°	240°	120°	0°	0,038	0,038	0,038		6,789	9,673	14,483
B	0°	120°	240°	120°	0°	240°	0,123	0,122	0,122		11,031	13,775	17,454

	III				**Magnetic Field**						
					x m from center / z m above ground				max(z m above ground)		
	phase configuration				-100 m / 0 m	-100 m / 1 m	-100 m / 2 m		max(0 m)	max(1 m)	max(2 m)
	R_A	**T_A**	**R_B**	**T_B**	µT	µT	µT		µT	µT	µT
C	0°	180°	180°	0°	0,018	0,018	0,018		11,115	14,589	19,349
D	0°	180°	0°	180°	0,152	0,152	0,151		9,856	12,027	15,450

	IV				**Magnetic Field**						
					x m from center / z m above ground				max(z m above ground)		
	phase configuration				-100 m / 0 m	-100 m / 1 m	-100 m / 2 m		max(0 m)	max(1 m)	max(2 m)
	R_A	**T_A**	**R_B**	**T_B**	µT	µT	µT		µT	µT	µT
C	0°	180°	180°	0°	0,018	0,018	0,018		6,844	9,714	14,510
D	0°	180°	0°	180°	0,126	0,126	0,126		7,051	8,504	10,797

Table 2: Summary of the calculation

Figure 6 shows the magnetic flux density in vertical direction along the Z-axis (x = 0 m) caused by tower I, phase configuration A and B. The marked horizontal bar shows the relevant area from 0 m up to 7,25 m under the power line, where the arrangement B is more favourable than A (lower magnetic flux density). This figure also reveals the influence of the height of the conductors. If the height of the conductors is increased, the phase configuration I/A (Table 1, Figure 3) produces less field in 0 m and 1 m above ground compared with phase configuration B.

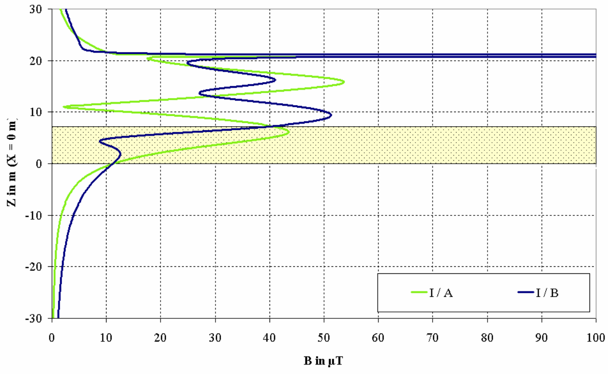

Figure 6: Magnetic flux density in vertical direction

In Figure 7 the change-over from the dark to the bright area shows where the flux density of variants I/A and I/B are equal.

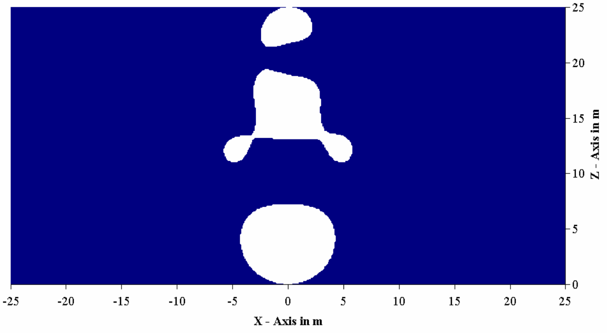

Figure 7: Comparison of case I/A – I/B

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[2] Calculation with BSCP, Institute of Electrical Power Systems, Friedl, Schmautzer. 2007

Within the bright area the magnetic flux density of case I/A is greater than the magnetic flux density of case I/B, within the dark area the magnetic flux density of case I/B is greater than the magnetic flux density of case I/A.

$$B_{P_{xy}} > B'_{P_{xy}} \text{ ... white; } B_{P_{xy}} < B'_{P_{xy}} \text{ ... dark} \quad \forall\, x\, 0 \ldots \pm 25,\ \forall\, y\, 0 \ldots \pm 25 \tag{12}$$

The configuration corresponding to case I/A provides a less magnetic flux density than case I/B.

The comparison of the crossed phase arrangement I/A with and without an overhead earth wire shows the influence of the homopolar current in the overhead earth wire and the resulting increase of the magnetic field in the far distance. In equ. (13) B means the case with an overhead earth wire and B´ the case without an overhead earth wire. Within the area directly under the power line the magnetic flux density is lower (even if only marginal), beyond that area the magnetic flux density is increasing, e.g. in 100 m it is almost twice so high.

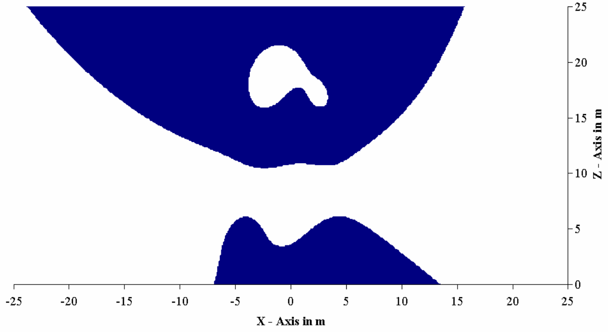

Figure 8: Comparison of case I/A with/without earth wire

The following Figure 9 shows the influence of different dimensions (conductor distances) of the tower head in an analogue way. The magnetic flux density for this specific fictitious compact power line (case II) is, up to approximately hundred meters from the axis, lower than the magnetic flux density of a standard power transmission line (case I).

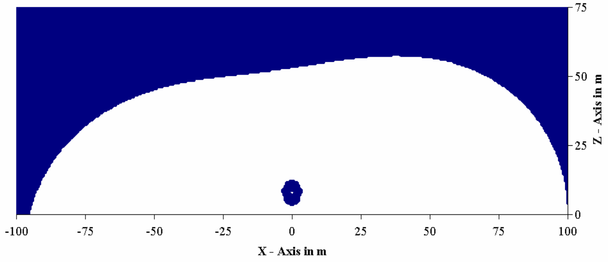

Figure 9: Comparison of case I/A – II/A

Summing up the results of Figure 6 … 9, Figure 10 shows the influence of the overhead earth wire and different phase configurations. In the far distance the homopolar earth wire causes higher magnetic flux densities compared with overhead power lines without earth wires.

The impact of the phase configuration is also remarkable and has to be considered carefully designing power lines.

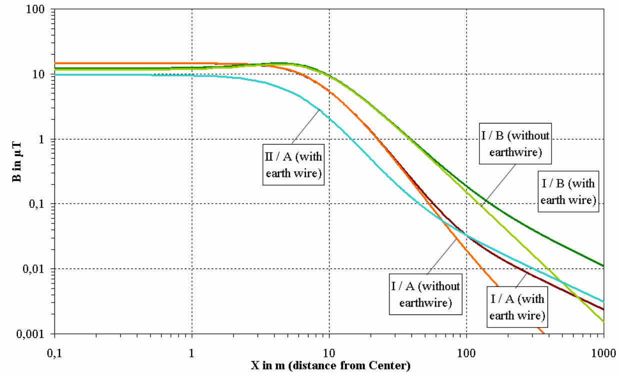

Figure 10: Influence of different configurations

CONCLUSION

As presented in the paper compact dimensions of tower heads, earth wires and an optimal phase configuration can reduce the magnetic flux density of 3 phase and 2 phase overhead transmission lines. The following key aspects can be summarized:

- The simplifying assumption, that a compact head of tower causes minor magnetic fields is not always admissible. Even a very compact profile of a power transmission line head has to be investigated carefully to find out in which area (close or far field) the magnetic flux density is reduced or increased.
- Currents in earth wires enlarge the magnetic flux density especially in the far magnetic field of an overhead transmission line.
- The optimisation of the phase configuration has to consider the effects on the close or far magnetic field.

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