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Electric and magnetic fields near power transmission lines as the function of temperature of wires

***Abstract**. Electric field intensity near power lines is the function of voltage and configuration of line, while magnetic field intensity is the function of flowing currents and of course configuration of line. The distance between wires and ground is the function of temperature of wires. The aim of the paper is finding the relationships between temperature of wires and electric field intensity and magnetic field intensity.*

***Streszczenie.** Natężenie pola elektrycznego w pobliżu linii elektroenergetycznych jest funkcją napięcia I konfiguracji linii, podczas gdy natężenie pola magnetycznego jest funkcją płynącego prądu I oczywiści też konfiguracji linii. Odległość pomiędzy przewodami i ziemią jest funkcją temperatury przewodów. Celem artykułu jest znalezienie zależności pomiędzy temperaturą przewodów a natężeniem pola elektrycznego i natężeniem pola magnetycznego. (**Pola elektryczne i magnetyczne w pobliżu linii elektroenergetycznych jako funkcja temperatury przewodów**).*

Keywords: power transmission line; electric field intensity; magnetic field intensity; temperature of wire.
Słowa kluczowe: linia elektroenergetyczna; natężenie pola elektrycznego, natężenie pola magnetycznego, temperatura przewodów.

Introduction

There are many methods of estimation of electric field (EF) intensity (E) and magnetic field (MF) intensity (H) near power transmission lines [1, 2]. The regular geometrical shape of transmission lines allows calculating precisely the EF intensity and MF intensity values. For determining the distribution of EF intensity around the line, the mirror reflection method and superposition method have been used. For calculating the MF intensity value the Biot-Savart's law and superposition methods have been used.

Electric field intensity near power lines is the function of voltage and configuration of line. The higher potential of wires, the bigger charge on wires and the higher electric field intensity. Besides the higher voltage of line the higher distances between wires are required. Therefore electric field intensity is higher, because the effect of "alone phase" is approximated. On the other hand the higher voltage the higher distance of wires to ground is required. It causes, that electric field intensity under wires is lower, but in some distances from line electric field intensity may be higher. The most important feature of electric field near lines is the small variability of rms value of EF intensity. The rms value of EF intensity is directly proportional to rms value of voltage of lines, which should be in range $\pm 0.1U_n$ or in narrower. However present currents in wires can have influence on EF intensity, because the higher currents cause the bigger sag and lower distances between wires and ground. Besides the higher currents cause the higher voltage drop. Additionally weather conditions (wind speed, temperature of air, solar radiation, humidity, air pressure) have influence on temperature of wires, which is responsible for sag.

From practical point of view the most important are values from regulations. According to Polish regulations [3] the highest permissible value of electric field intensity in natural environment is 10 kV/m. Besides in the range, where E > 1 kV/m building of houses is prohibited.

MF intensity near power lines is the function of flowing currents and configuration of line. MF intensity is proportional to flowing currents. The rms value of MF intensity changes in big range, because the rms values of currents in phase wires change from $I \approx 0$ to current-carrying capacity of lines (I_{cc}). The permissible value of MF intensity in natural environment is equal to 60 A/m [3]. The same value (60 A/m) is permissible in places appropriated for the public building [3]. The analysis for different lines is similar, therefore the analysis is done for the typical 220 kV line on towers H52.

Span of typical power line

The typical 220 kV line on tower H52 has the wire AFL-8 525 mm^2, and two ground wires AFL-1,7 70 mm^2. Table 1 contains the characteristic parameters for the span. The first step is calculation of fissure span a_p:

$$a_p = \sigma_0 \sqrt{\frac{480\alpha}{g_{p+s}^2 - g_p^2}} \tag{1}$$

Specific weight of hoar-frost g_s:

$$g_s = \frac{G_s}{S} \tag{2}$$

where: $G_S = 2.75+0.275d$ – linear weight of hoar-frost. The specific weight of wire with hoar-frost:

$$g_{p+s} = g_p + g_s \tag{3}$$

If $a > a_p$, then the highest stress is for the hoar-frost. Therefore the initial conditions are for the state hoar-frost and the highest calculation stress σ_0 = 90 Mpa occurs for the hoar-frost. The stress σ for the given temperature t_1 can be estimated from the following equation:

$$\sigma^2(\sigma + A) = B \tag{4}$$

where:

$$A = \frac{a^2 g_0^2}{24\beta\sigma_0^2} + \frac{\alpha}{\beta}(t_1 - t_0) - \sigma_0 \qquad B = \frac{a^2 g_1^2}{24\beta} \tag{5}$$

Index "0" is for the initial conditions (state hoar-frost):

$$g_0 = g_{p+s}, t_0 = -5°C, \sigma_0 = 90\ MPa \tag{6}$$

For other temperatures $g_1 = g_p$. The sag can be estimated from the following relationship:

$$f = \frac{a^2 g_1}{8\sigma} \tag{7}$$

Table 1. Span of the 220 кV line on tower H52

Category	Symbol	Value	Unit
Nominal length of span	a	450	m
Phase wires AFL-8 525 mm^2			
Calculation stress of wires	σ_0	90	Mpa
Specific weight of wire	g_p	$32.93 \cdot 10^{-3}$	$\frac{N}{(m \cdot mm^2)}$
Calculation diameter	d	31.5	mm
Total calculation cross-section	S	586.9	mm^2
Coefficient of thermal extension	α	$19.4 \cdot 10^{-6}$	1/^{o}C
Coefficient of elastic extension	β	$14.03 \cdot 10^{-6}$	1/Pa
Resistance of wire for 20^{o}C	R_{20}	0.0564	Ω/km
Ground wires AFL-1,7 70 mm^2			
Calculation stress of wires	σ_0	190	Mpa
Specific weight of wire	g_p	$46.0 \cdot 10^{-3}$	$\frac{N}{(m \cdot mm^2)}$
Calculation diameter	d	12.75	mm
Total calculation cross-section	S	97.03	mm^2
Coefficient of thermal extension	α	$15.2 \cdot 10^{-6}$	1/^{o}C
Coefficient of elastic extension	β	$9.31 \cdot 10^{-6}$	1/Pa
Resistance of wire for 20^{o}C	R_{20}	0.4777	Ω/km

Relationship (7) is the function of the temperature of wire, because (5) is function of temperature of wire. On the other hand the temperature of wires is the function of current, sun radiation, wind speed and temperature of air. Therefore temperature of conductor changes in quite wide range. The thermal static balance of conductor can be expressed by the following equation:

(8) $$P_i + P_s = P_c + P_r$$

where: P_i - power produced by current flow, P_S - power absorbed from sun radiation, P_c - power of convection, P_r - power of radiation. Total thermal power absorbed from sun radiation P_s can be calculated from the relationship:

(9) $$P_s = \alpha_S Q_S D_w$$

where: α_S – absorption coefficient of conductor surface, Q_s – solar radiation, D_w – external diameter of conductor.

P_c and P_r are functions of temperature of environment t_{EN} and temperature of conductor t_w:

(10) $$P_c = \pi\lambda(t_w - t_{EN})Nu$$

(11) $$P_r = \pi D_w \varepsilon \delta_B \left[(t_w + 273)^4 - (t_{EN} + 273)^4\right]$$

where: λ - thermal conductivity of air, ε - thermal emission factor, δ_B – Stefan-Boltzmann's constant. Nusselts number *Nu* is related to Reynolds number *Re*:

(12) $$Nu = B(Re)^n$$

where: B, n – coefficients, which are the function of Reynold's number Re. Reynold's number is the function of wind speed:

(13) $$Re = \frac{\rho v D_w}{\nu}$$

where: ρ - air density, ν - viscosity of air, v - wind speed. Table 2 presents physical properties of air. Table 3 presents values of coefficients B and n.

Power produced by current flow (P_i) can be calculated from the following relation:

(14) $$P_i = I^2 R$$

where: R – resistance of conductor in given temperature:

(15) $$R = R_{20}(1 + \alpha\Delta t)$$

where R_{20} – resistance of conductor in temperature 20°C.

Relations (8) and (9), (10), (11), (14) enable estimation of temperature of wire t_w.

Table 2. Physical properties of air

T	t	ρ	λ	υ
K	^{o}C	kg/m^3	W/(m·K)	m^2/s
273	0	1,293	0,0244	0,00001328
278	5	1,270	0,0248	0,00001372
283	10	1,247	0,0251	0,00001416
288	15	1,226	0,0255	0,00001461
293	20	1,205	0,0259	0,00001506
298	25	1,185	0,0263	0,00001553
303	30	1,165	0,0267	0,00001600
308	35	1,147	0,0271	0,00001648
313	40	1,128	0,0276	0,00001696

Table 3. Values of coefficients B and n

Roughness Rs	Reynold's number *Re*		B	n
	from	to		
Any wire	100	2650	0,641	0,471
Rs ≤ 0,05	2650	50000	0,178	0,633
Rs ≥ 0,05	2650	50000	0,048	0,800

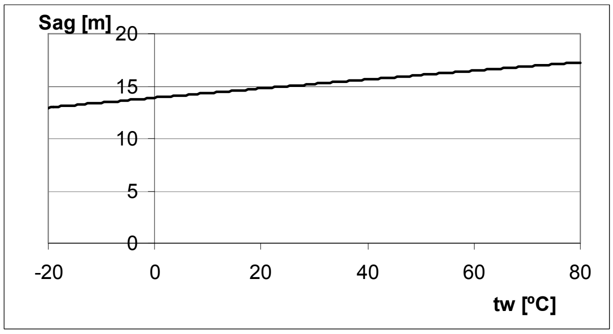

Fig. 1. Sag of the phase wire as the function of temperature of wire t_w

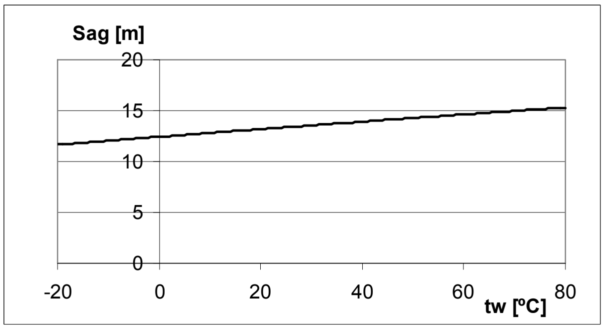

Fig. 2. Sag of the ground wire as the function of temperature of wire t_w

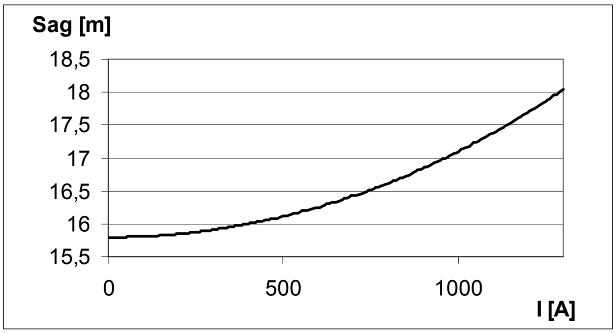

Fig. 3. Sag of the phase wire as the function of current *I*

Distance of wires to ground

The sag can be estimated as the function of temperature of wires. The temperature of wire is the function of weather conditions and currents. Figure 1 presents the sag of the phase wire as the function of temperature of wire t_w. Figure 2 presents the sag of the ground wire as the function of temperature of wire.

Figure 3 shows sag as the function of current in phase wire for temperature of environment t_{EN} = 30^{o}C, wind speed v = 0.5 m/s, absorption coefficient of conductor surface α_S = 0.8, thermal emission factor ε = 0.8, solar radiation Q = 900 W/m^2.

Table 4 shows the distances between wires and ground (h) for phase wire and ground wire as the function of temperature of wire. The highest sag is for temperature of wire t_w = 80^{o}C. In this place the following assumptions is established: the distance of phase wire to ground for t_w = 80^{o}C is equal to the lowest permissible value h_{min} = 5 + D_{el} = 6,7 m, where D_{el} = 1,7 m according to European Standards [4, 5].

Table 4. Distances of wires to ground

Temperature of wire t_w [^{o}C]	Phase wire		Ground wire	
	Sag [m]	*h* [m]	Sag [m]	*h* [m]
80	17.26	6.70	15.30	11.2
70	16.86	7.10	14.96	11.54
60	16.46	7.50	14.62	11.88
50	16.05	7.91	14.27	12.33
40	15.63	8.33	13.91	12.59
30	15.20	8.76	13.55	12.95
20	14.77	9.19	13.18	13.32
10	14.33	9.63	12.80	13.70
0	13.87	10.09	12.42	14.08
-10	13.41	10.55	12.04	14.46
-20	12.95	11.01	11.65	14.85

Table 5 presents configuration of line for the temperature of wires 80^{o}C. The highest permissible voltage for 220 kV line is 245 kV, therefore the phase voltage is 141.5 kV.

Table 5. Configuration of 220 kV line

Wire	Voltage [kV]	Distance from axis [m]	*h* [m]
L1 525	141.5	-7.6	6.70
L2 525	141.5	0	6.70
L3 525	141.5	7.6	6.70
Ground w. 70	0	-5.6	11.2
Ground w. 70	0	5.6	11.2

Electric field intensity near line

Figure 4 shows electric field intensity for different temperature of wires. Figure 5 presents the highest values of electric field intensity as the function of temperature of wires.

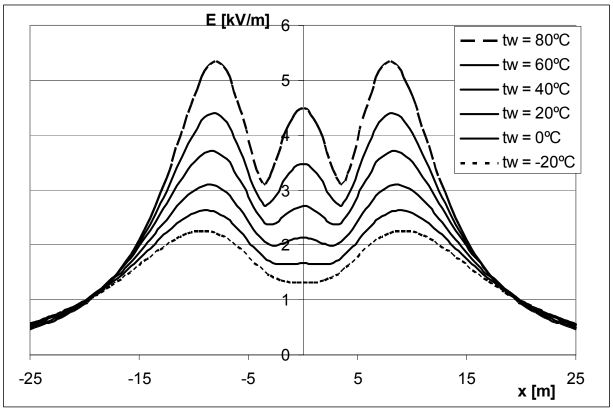

Fig. 4. Electric field intensity near 220 kV line for different temperatures of wires (t_w = 80^{o}C – the highest E, t_w = -20^{o}C – the lowest E)

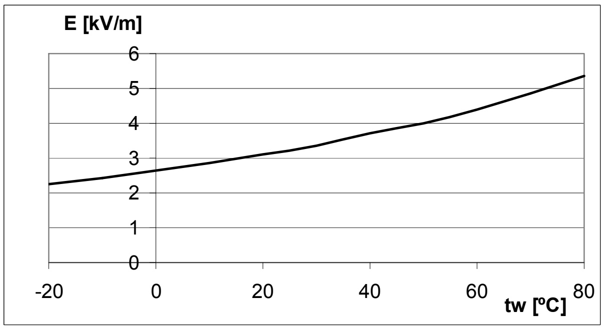

Fig. 5. The highest values of electric field intensity near 220 kV line for different temperatures of wires

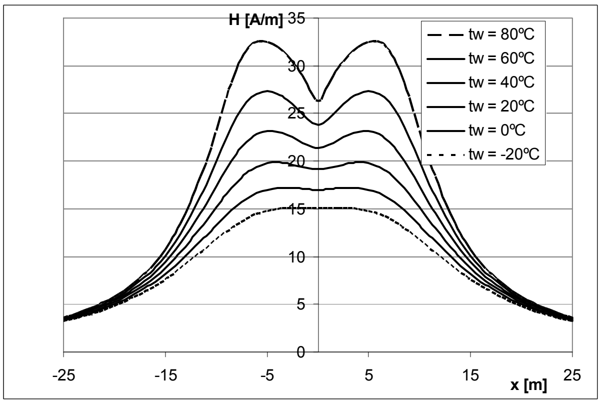

Fig. 6. Magnetic field intensity near 220 kV line for different temperatures of wires (t_w = 80^{o}C – the highest H, t_w = -20^{o}C – the lowest H)

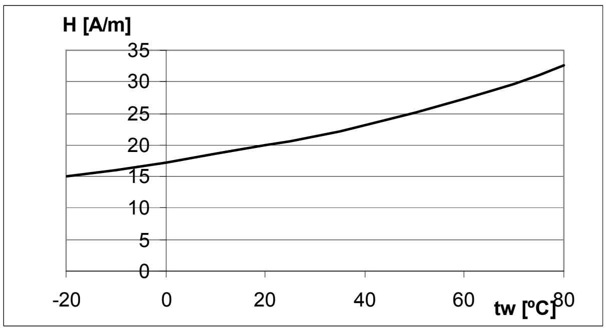

Fig. 7. The highest values of magnetic field intensity near 220 kV line for different temperatures of wires

Magnetic field intensity near line

Magnetic field intensity near power transmission line is the function of configuration and currents flowing in wires. The results of calculations presented in figure 6 have been done for the current I = 1000 A. Fig. 7 presents the highest values of magnetic field intensity as the function of temperature for the same value of flowing current I = 1000 A.

Conclusions

Presented analysis has shown that temperature of wire has some essential influence on EF intensity and MF intensity near power transmission lines. Generally EF and MF intensities are the raising function of temperature of wires.

Influence of temperature of wire on EF intensity is very simple for explanation. The situation is not so simple for MF intensity, because on one hand side MF intensity is function of flowing currents but these currents have influence on temperature of wire and of course on sag. Therefore in real environmental condition there must be sometimes a special relation between currents, solar radiation, wind speed and temperature of environment in order to ensure exact value of temperature of wires. For example for low wind speed, high solar radiation, high temperature of environment the current can be too high and can exceed current carrying capacity of phase wire.

The above presented analysis shows, that it is very difficult to estimate EF intensity and MF intensity near power transmission lines in real environmental conditions using only measuring apparatus. In order to estimate exactly the highest values of EF and MF intensities and the places appropriated for buildings the additional calculations should be done.

Besides such the analysis is very helpful for selection of suitable type and series of tower.

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