ENVIRONMENTAL IMPACTS OF OVERHEAD LINES

Impacts:

- property of the land
- esthetic (area view)
- ecological (flora, fauna, water)
- technical (EMC, disturbances)
- health
    - electrical field
    - magnetic field
    - noise

x efforts to increase transmission capacity

Safety areas for overhead lines =
space defined by vertical planes on both sides of the line within a horizontal distance measured perpendicular to the lines. Distance is from the outer line conductors on both sides.

For conductors without insulation:

a) U from 1 kV up to 35 kV – 7 m,
b) U from 35 kV up to 110 kV – 12 m,
c) U from 110 kV up to 220 kV – 15 m,
d) U from 220 kV up to 400 kV – 20 m,
e) U more than 400 kV – 30 m.

Impact of el-mag. field generated by overhead line

Impact of low frequency field (50, 60 Hz) on animals and human beings has been researched for last 50 years.
Many studies (impact on molecular mechanisms, genetical changes, diseases) – statistical problems, not clear results (low correlation).

- el. field – causes charges and currents at surface, living tissue reduces el. field (by 8 orders), the inside level lower than in cells
- mag. field –induced el. field, circulating currents
- field energy – absorbed by living matter

Even research results are not clear standards for lines impact exist:

- ENV 50166-1: Human exposure to electromagnetic field; Low frequency (0 Hz to 10 kHz). CENELEC 1995
  - 50 Hz limit values, public
    - $E_{max} = 10 \ kV/m$
    - $B_{max} = 640 \ \mu T$

- 50 Hz limit values, employees
  - $E_{max} = 30 \ kV/m$
  - $B_{max} = 1600 \ \mu T$
- Directive ICNIRP (International Commission on Non-Ionizing Radiation Protection) from 1999, authorized by WHO
  - 50 Hz, permanent people exposition
  - public
    - $E_{max} = 5 \ kV/m$
    - $B_{max} = 100 \ \mu T$
  - employees
    - $E_{max} = 10 \ kV/m$
    - $B_{max} = 500 \ \mu T$

- CR: Government decree 1/2008 Sb. about health protection against non-ionizing radiation
  - reference values E_{max}, B_{max} (measurable) for 50 Hz – they ensure not-exceeding the highest admissible values of induced current densities in a body J_{max}
  - public
    - $J_{max} = 2 \ \ mA/m^2$
    - $E_{max} = 5 \ \ kV/m$
    - $B_{max} = 100 \ \ \mu T$
  - empolyees
    - $J_{max} = 10 \ \ mA/m^2$
    - $E_{max} = 10 \ \ kV/m$
    - $B_{max} = 500 \ \ \mu T$

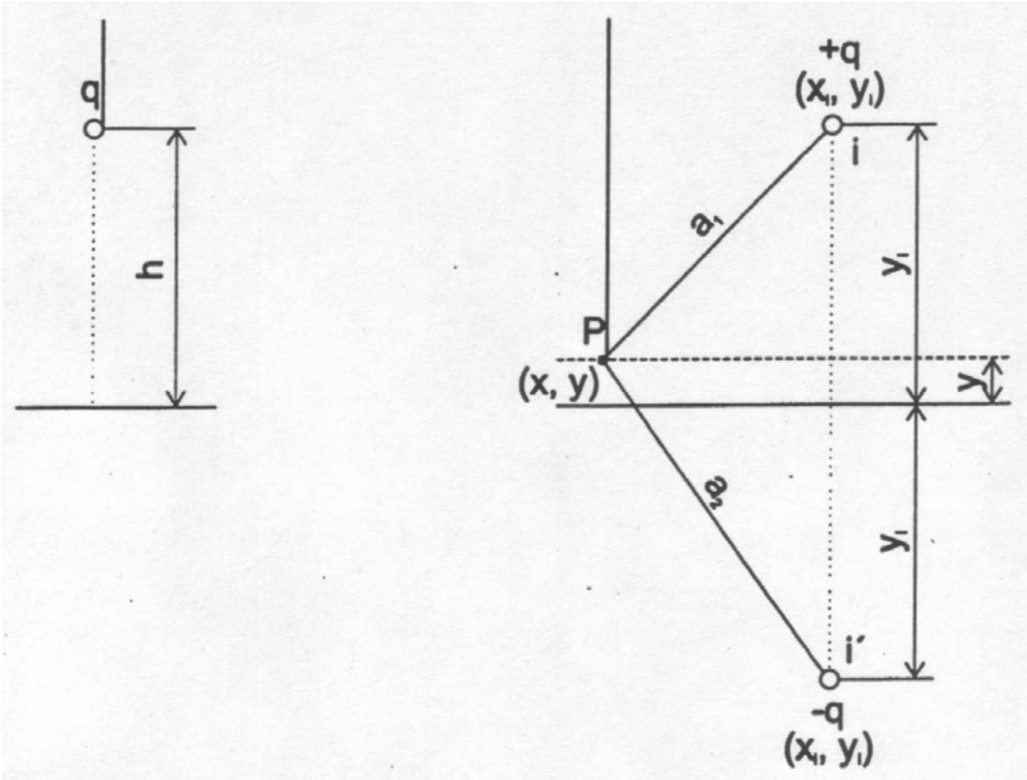
- if exceeding the reference values E, B, measurement on human body models are done if maximal J values are not exceeded

- ČSN 332040 (1993) – Protection against impacts of electromagnetic field of 50 Hz in an impact zone of electrical system equipment
  - workers with electrotechnical qualification at control routes and in working place: $E_{max} = 15 \ \ kV/m$
  - $E_{max} = 15 \div 20 \ kV/m$ → 1,5 hour/day
  - $E_{max} = 20 \div 25 \ kV/m$ → 0,5 hour/day
  - zone of power engineering equipment impact with public access
    - $E_{max} = 10 \ \ kV/m$
    - $B_{max} = 500 \ \ \mu T$
  - impact zone of electrical equipment impact is area where
    - $E > 1 \ \ kV/m$ at 1,8 m high
    - $B > 100 \ \ \mu T$ at 1,0 m high

Electrical field calculation

Configuration:

- line conductors with linear electrical charge density q (C/m)
- ground is equipotential surface (U = 0) → mirror method



Potential in any point $P_{(x,y)}$ above the ground

$$\varphi_P = \frac{q}{2\pi\varepsilon_0} \ln \frac{a_2}{a_1} \quad (V)$$

ε_0 ..... permittivity of vacuum

$$\varepsilon_0 = 8{,}854 \cdot 10^{-12}\ F/m \ \approx\ 10^{-9}/36\pi\ F/m$$

$$\varphi_P = \frac{q_i}{4\pi\varepsilon_0} \ln \frac{(x - x_i)^2 + (y - y_i)^2}{(x - x_i)^2 + (y + y_i)^2}$$

We know voltage, one conductor is solved directly:

$$u_i = \frac{q_i}{2\pi\varepsilon_0} \ln \frac{2y_i}{r_i}$$

Multi conductor system (ground wires are included, $u_z = 0$) – method of capacity calculation is used.

$$(u) = (\delta)(q)$$

$$(q) = (\delta)^{-1}(u)$$

Potential coefficient

$$\delta_{i,i} = \frac{1}{2\pi\varepsilon_0}\ln\frac{2y_i}{r_i}$$

$$\delta_{i,j} = \frac{1}{2\pi\varepsilon_0}\ln\frac{\sqrt{4y_i y_j + d_{i,j}^2}}{d_{i,j}}$$

Total potential in the point P

$$\varphi_P = \sum_{i=1}^{n}\frac{q_i}{2\pi\varepsilon_0}\ln\frac{a_{2i}}{a_{1i}} \quad (V)$$

Intensity of electrical field:

$$\vec{E} = -\text{grad}\,\varphi \quad (V/m)$$

$$E_x = -\frac{\partial \varphi_P}{\partial x}, \quad E_y = -\frac{\partial \varphi_P}{\partial y}$$

$$E = \sqrt{E_x^2 + E_y^2}, \quad \vec{E} = E_x + jE_y$$

Alternatively separately for each conductor (also the mirror conductors)

$$\oiint \vec{D}\,d\vec{S} = Q$$

$$\varepsilon E \cdot 2\pi r l = q \cdot l$$

$$E = \frac{q}{2\pi\varepsilon r}$$

$$E_{x\Sigma} = \sum_{i=1}^{n} E_{xi}, \quad E_{y\Sigma} = \sum_{i=1}^{n} E_{yi}$$

Voltage, charge and electrical field are changing in time (also phase shifts!)

$$\left(q(t)\right) = \left(\delta\right)^{-1}\left(u(t)\right)$$

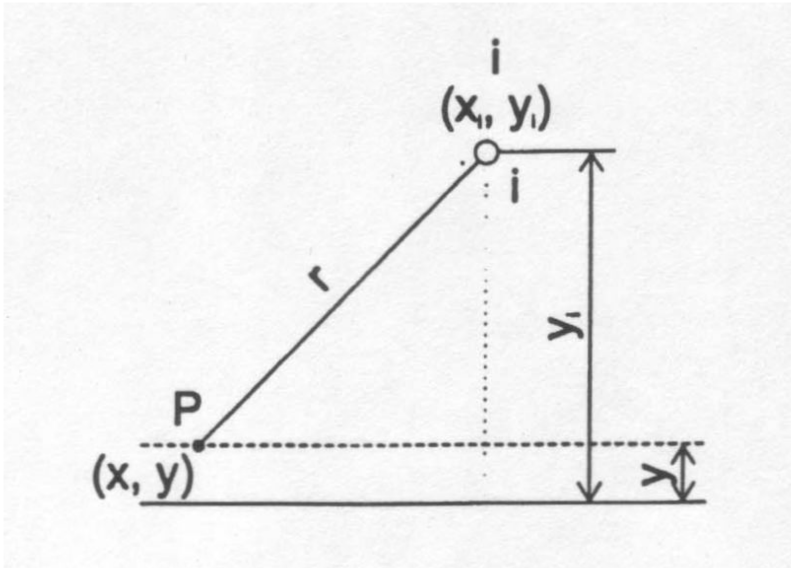
$$\left(\hat{Q}\right) = \left(\delta\right)^{-1}\left(\hat{U}\right)$$

Magnetic field calculation

Configuration:

- linear conductors are loaded by current i (A)
- currents in ground wires are calculated by means of impedance matrix

$$\begin{pmatrix} \Delta\hat{U}_v \\ 0 \end{pmatrix} = \begin{pmatrix} \hat{Z}_{vv} & \hat{Z}_{vz} \\ \hat{Z}_{zv} & \hat{Z}_{zz} \end{pmatrix} \begin{pmatrix} \hat{I}_v \\ \hat{I}_z \end{pmatrix}$$



Ampere's law

$$\oint \vec{H} \cdot d\vec{l} = I$$

Magnetic induction in the point $P_{(x,y)}$ outside conductor

$$B = \frac{\mu_0 i}{2\pi r} \quad (T)$$

μ_0..... permeability of vacuum

$$\mu_0 = 4\pi \cdot 10^{-7} \ H/m$$

Components

$$B_x = \pm B \cdot \sin\left(\operatorname{arctg}\left| \frac{y_i - y}{x_i - x} \right| \right)$$

$$B_y = \pm B \cdot \cos\left(\operatorname{arctg}\left| \frac{y_i - y}{x_i - x} \right| \right)$$

Total values in the point P

$$B_{x\Sigma} = \sum_{i=1}^{n} B_{xi} \,, \quad B_{y\Sigma} = \sum_{i=1}^{n} B_{yi}$$

$$B_{\Sigma} = \sqrt{B_{x\Sigma}^2 + B_{y\Sigma}^2} \,, \quad \vec{B}_{\Sigma} = B_{x\Sigma} + jB_{y\Sigma}$$

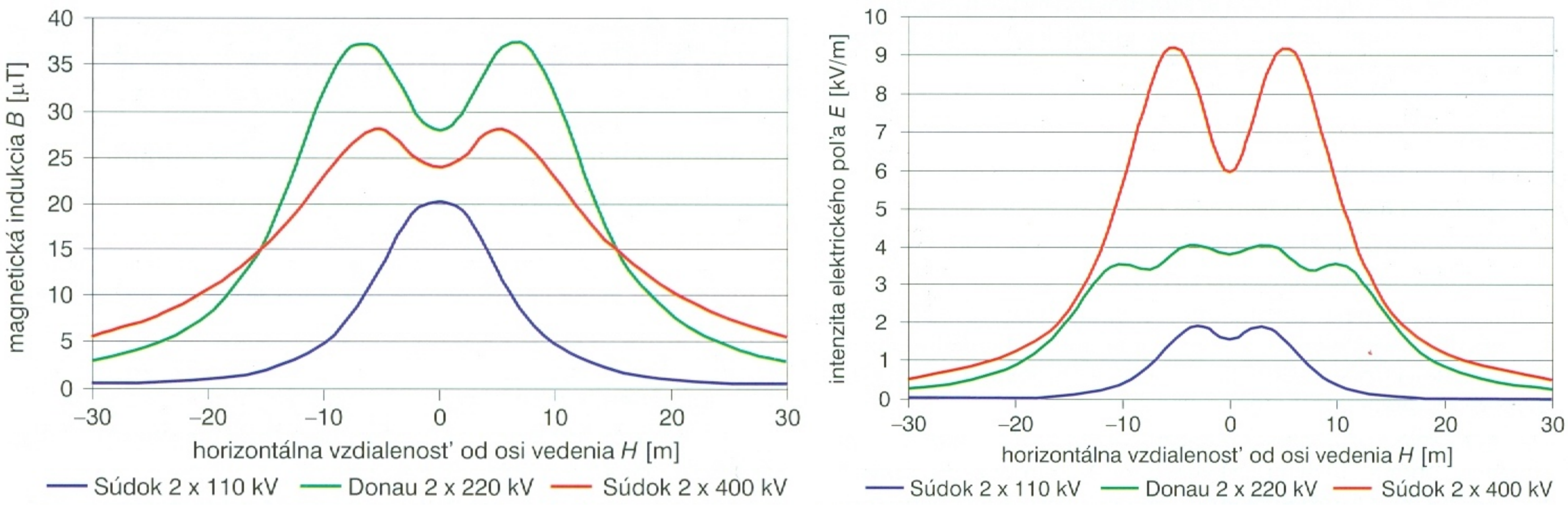
Current and magnetic field are changing in time.

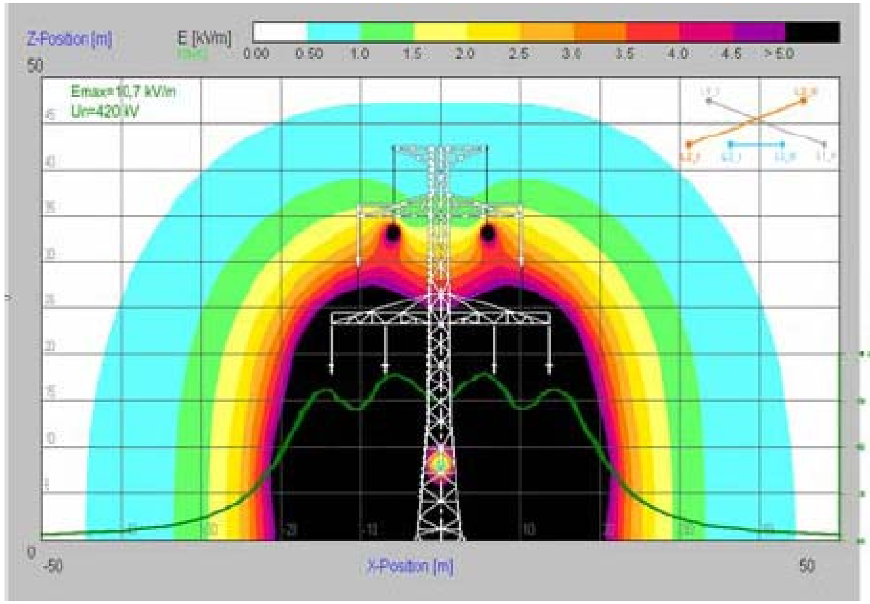
$$B(t) = \frac{\mu_0 i(t)}{2\pi r} \quad (T)$$

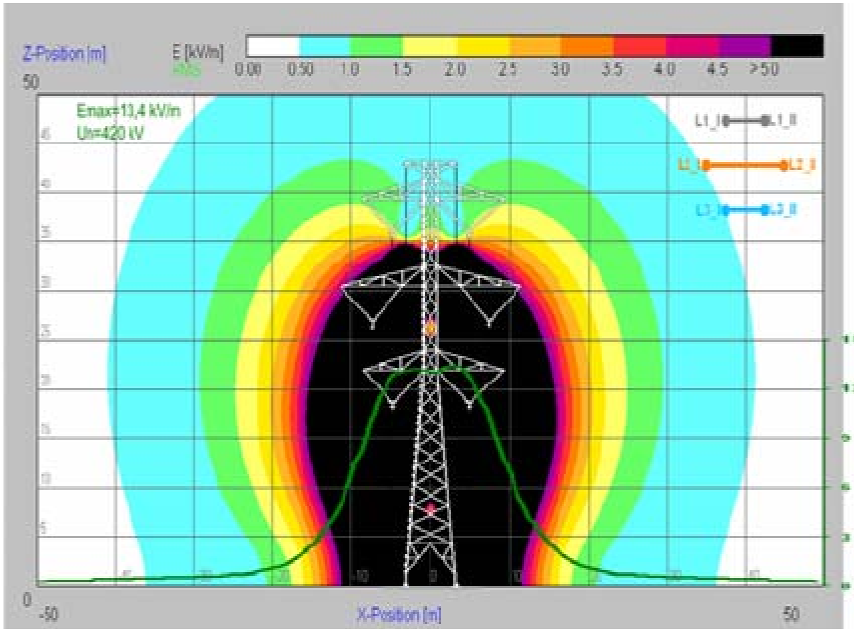
In term of el-mag. field impact there are 2 tasks:

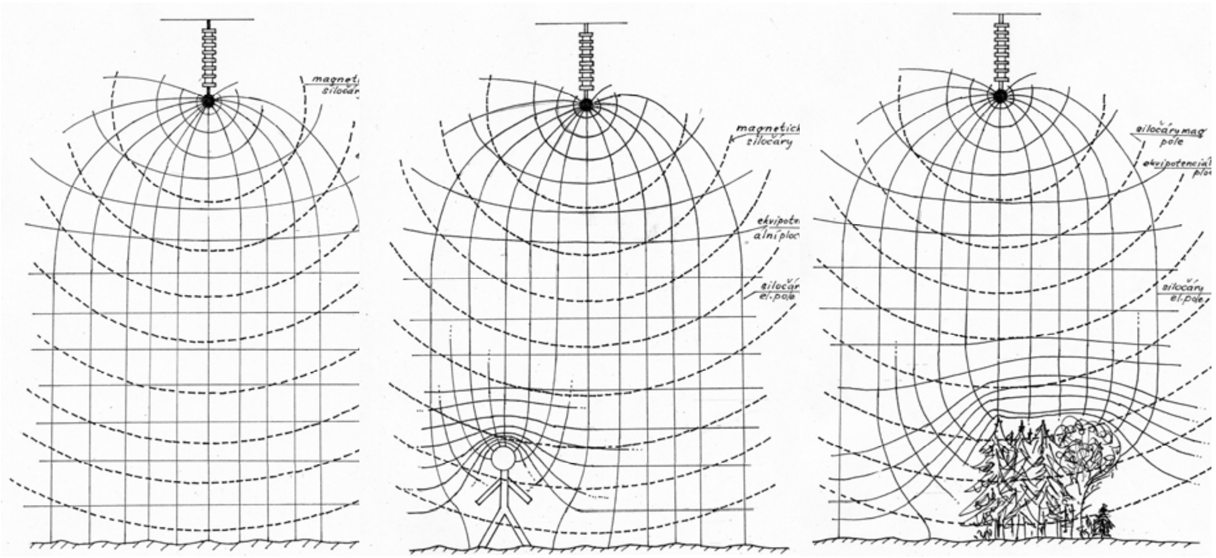
- Maximum value at given area (cross-section under the line)
- Optimization of the line to minimize field characteristics

Barrel 2 x 110 kV, 650 A, conductor min. 6 m above the ground
Donau 2 x 220 kV, 1000 A, conductor min. 7 m above the ground
Barrel 2 x 400 kV, 1000 A, conductor min. 8 m above the ground



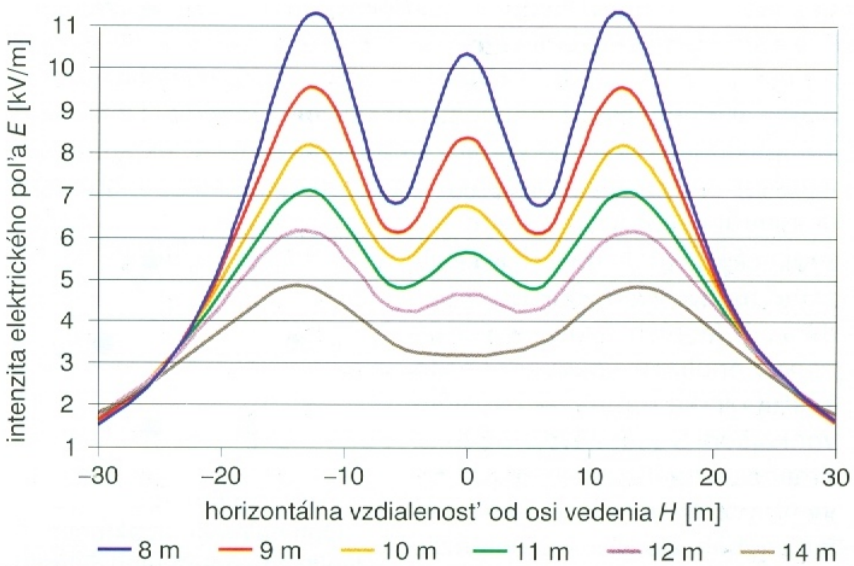

Z-Position [m]
E [kV/m]
0.00 0.50 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 > 5.0
Emax=10,7 kV/m
Un=420 kV
X-Position [m]
Electric field intensity E [kV/m]


Z-Position [m]
E [kV/m]
0.00 0.50 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 >5.0
Emax=13,4 kV/m
Un=420 kV
X-Position [m]
Electric field intensity E [kV/m]

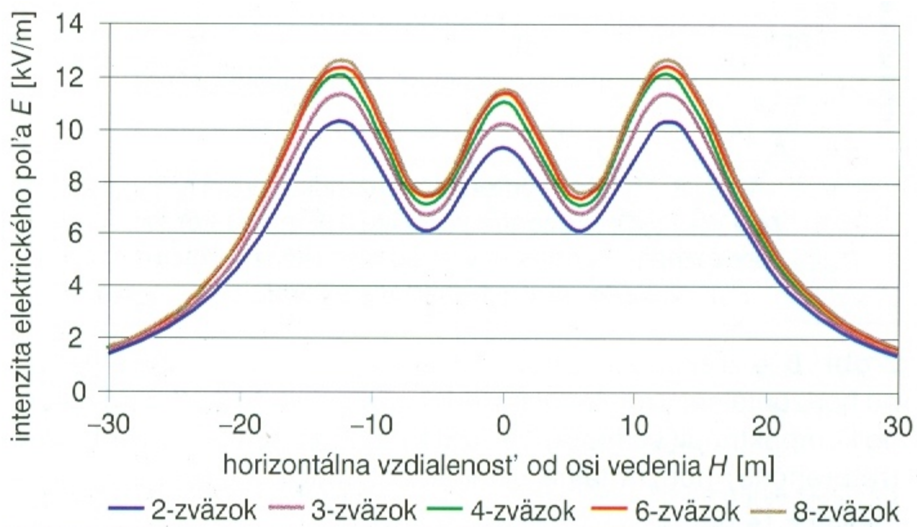

siločáry mag. pole

Electrical field control

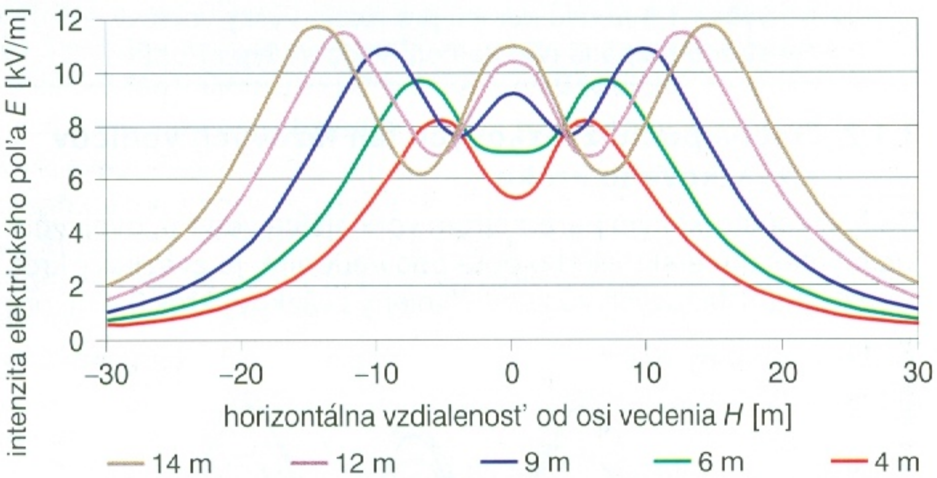
- increase of phase conductors distance from the ground *x mech. tension*
- voltage level decrease – limits up to ±5 %, ±10 % *x power losses*
- number of bundle conductors and bundle step – smaller step *x corona*
- conductors distance (line compactness) *x safety*
- phase sequence – at multiple lines
- shielding wires under the line – also buildings or vegetation



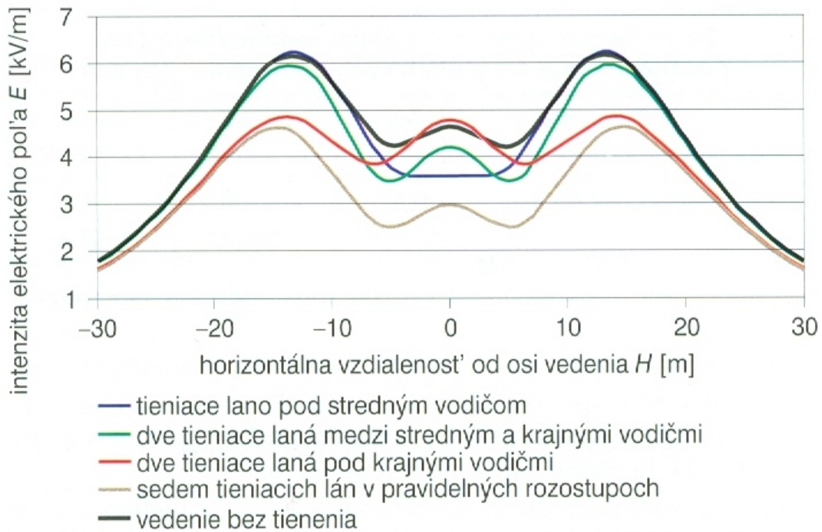
Obr. 5. Priebehy intenzity elektrického poľa *E* vo výške 1,8 m nad zemou pre rôzne výšky vodičov v strede rozpätia nad zemou, vedenie typu Portál



Obr. 6. Priebehy intenzity elektrického poľa *E* pod vonkajším vedením typu Portál vo výške 1,8 m nad zemou pre rôzne počty zväzkových lán pri minimálnej výške fázových vodičov v strede rozpätia nad zemou 8 m



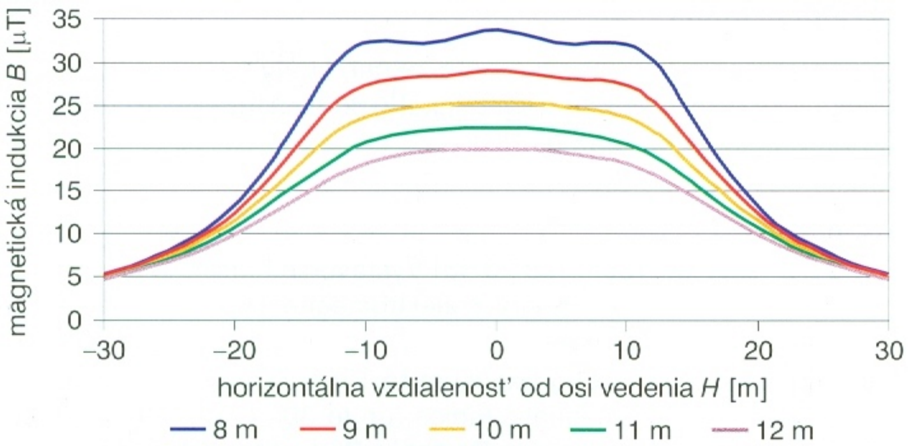
Obr. 8. Priebehy intenzity elektrického poľa *E* pod vonkajším vedením vo výške 1,8 m nad zemou pre rôzne horizontálne vzdialenosti medzi vodičmi vedenia 1 × 400 kV typu Portál



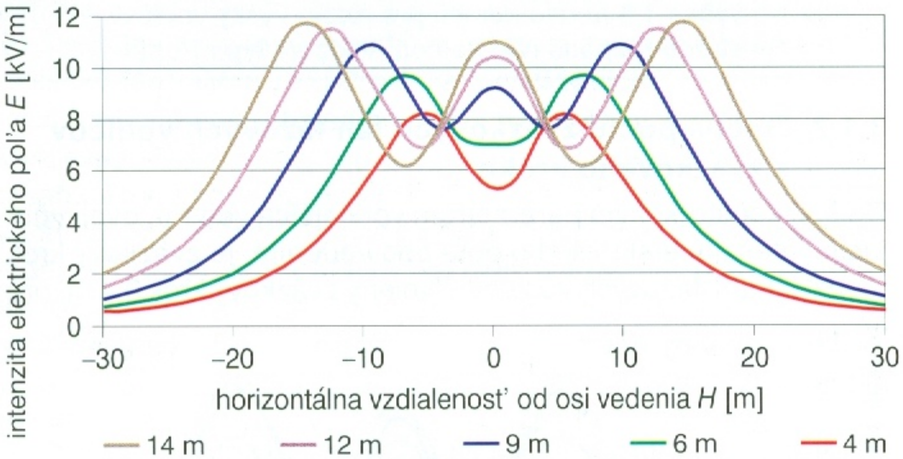
Obr. 9. Účinok tieniacich lán inštalovaných 4 m pod fázovými vodičmi vedenia 1 × 400 kV typu Portál na rozloženie intenzity elektrického poľa *E*

Magnetic field control

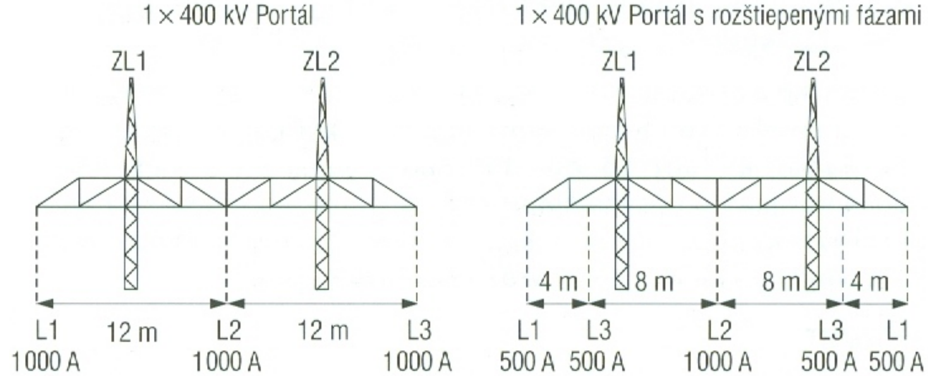
- increase of phase conductors distance from the ground
- current decrease
- conductors distance (line compactness) *x safety*
- coupling conductors, split phase
- shielding wires with induced currents
- phase sequence – at multiple lines



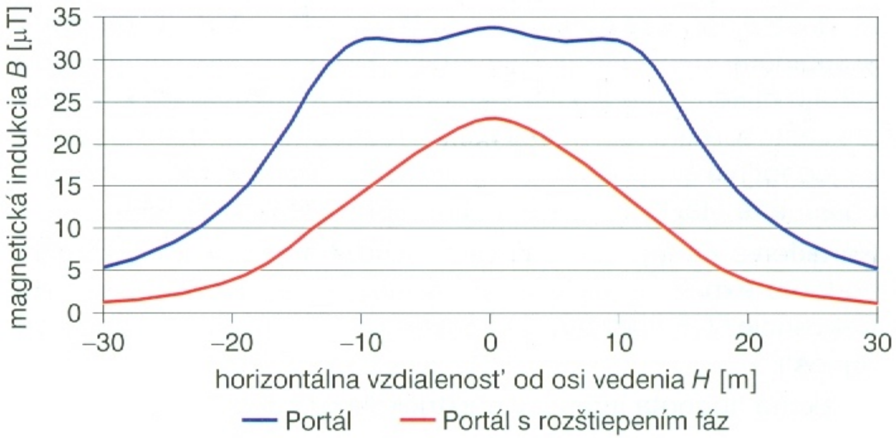
Obr. 11. Priebehy magnetickej indukcie *B* vo výške 1,8 m nad zemou pre rôzne výšky fázových vodičov vedenia 1 × 400 kV typu Portál nad zemou



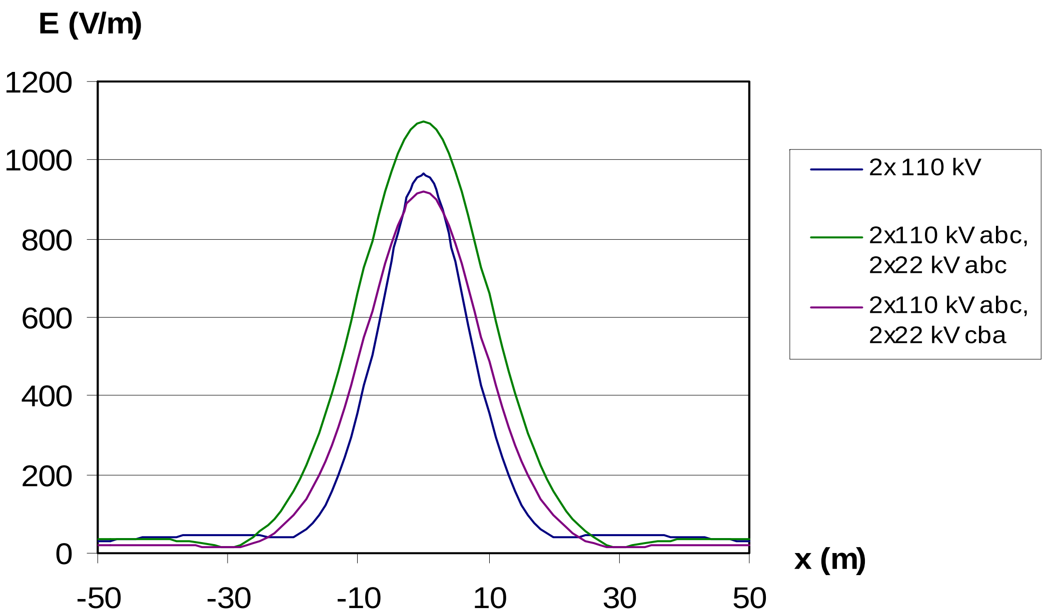
Obr. 8. Priebehy intenzity elektrického poľa *E* pod vonkajším vedením vo výške 1,8 m nad zemou pre rôzne horizontálne vzdialenosti medzi vodičmi vedenia 1 × 400 kV typu Portál

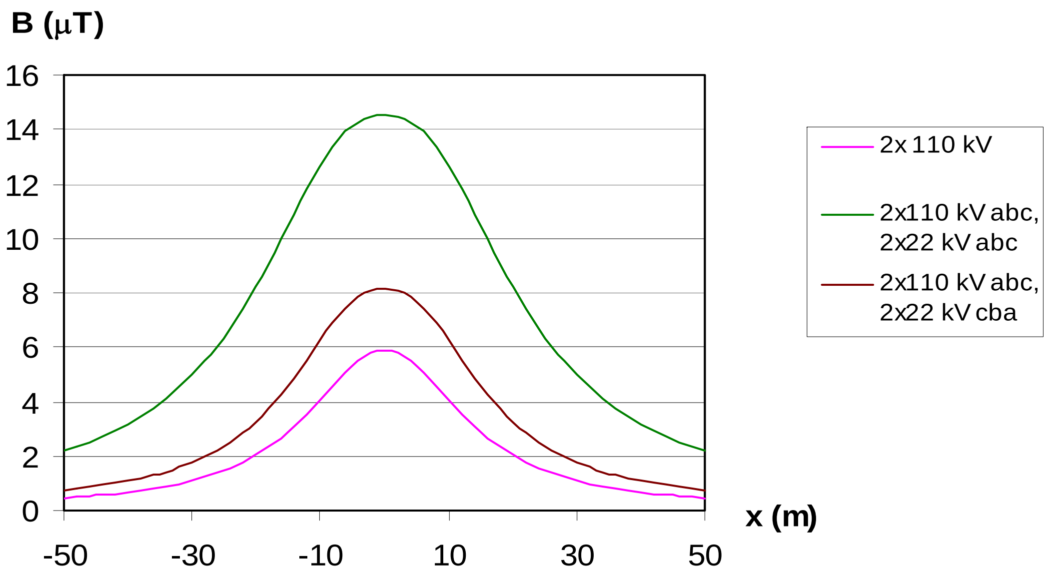


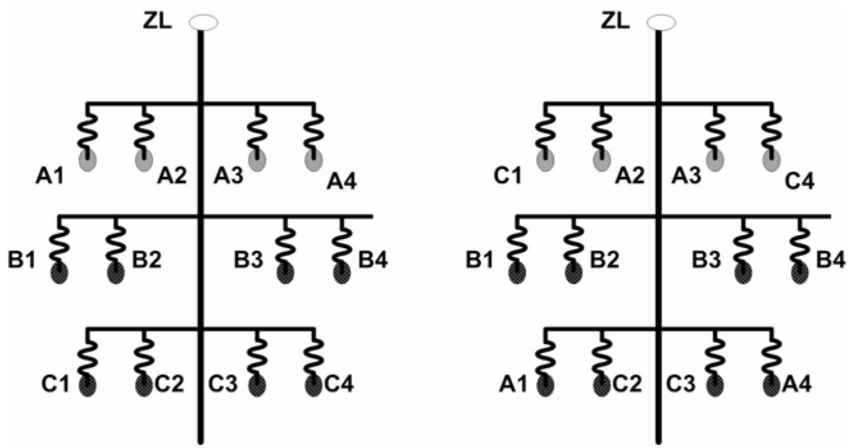
Obr. 13. Možné spôsoby riešenia rozštiepenia prúdov všetkých troch fáz

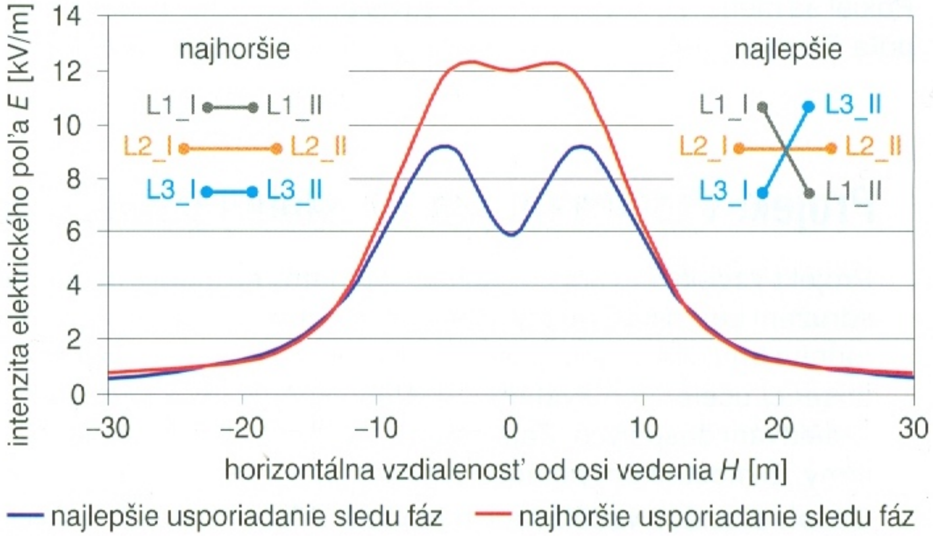


Obr. 14. Vplyv rozštiepenia fáz L1 a L3 na úroveň magnetickej indukcie *B* vo výške 1,8 m nad zemou v strede horizontálneho rozpätia stožiara typu Portál

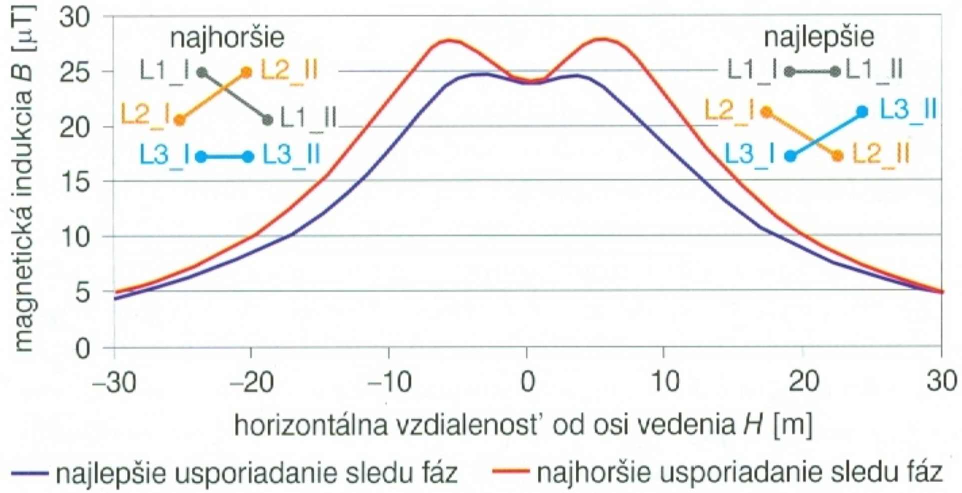

E (V/m)
1200
1000
800
600
400
200
0
-50
-30
-10
10
30
50
x (m)
2x 110 kV
2x110 kV abc, 2x22 kV abc
2x110 kV abc, 2x22 kV cba


B (μT)
16
14
12
10
8
6
4
2
0
-50
-30
-10
10
30
50
x (m)
2x 110 kV
2x110 kV abc, 2x22 kV abc
2x110 kV abc, 2x22 kV cba


ZL
A1
A2
A3
A4
B1
B2
B3
B4
C1
C2
C3
C4
ZL
C1
A2
A3
C4
B1
B2
B3
B4
A1
C2
C3
A4



Obr. 15. Vplyv zmeny sledu fáz na úroveň intenzity elektrického poľa *E* pod vonkajším vedením 2 × 400 kV typu Súdok vo výške 1,8 m nad zemou pri najmenšej výške vodičov 8 m nad zemou v strede rozpätia



Obr. 16. Vplyv zmeny sledu fáz na úroveň magnetickej indukcie *B* pod vonkajším vedením 2 × 400 kV typu Súdok vo výške 1,8 m nad zemou pri výške vodičov 8 m nad zemou v strede rozpätia

Overhead line audible noise

Excessive noise – influence on neural and cardiovascular systems, deteriorate learning ability, memory, communication,…

Legislation

- recommendation of WHO 55dB for outdoor areas at day time
- Day time 6:00 – 22:00, night time.
- Overhead lines = other stationary sources of noise
  - For outdoor area:
    $L_{Aday} = L_{Anight} = 50$ dB
  - For protected outdoor building areas:
    $L_{Aden} = 50$ dB, $L_{Anoc} = 40$ dB

Noise level from sources

Equivalent sound level (A)

$$L_{Aeq} = 10\log\frac{1}{T}\int_{t_1}^{t_2}\left(\frac{p_A(t)}{p_0}\right)^2 dt \quad (dB)$$

$p_A(t)$ .... (Pa) is continues RMS value of acoustic pressure time function scaled to frequency correction curve A (corresponding to human perception)

T (s) .... integration period, $T = t_2 - t_1$

p_0......... referential acoustic pressure (audibility limit for average person) $p_0 = 2.10^{-5}$ Pa

Sound intensity I (it can be added linearly from more sources)

$$I = \frac{P}{S} (W/m^2)$$

Generally $I \sim p^2$. Hence

$$L_I = 10 \log \frac{I}{I_0} \quad \text{(dB)}$$

I_0 .... audibility limit

$I_0 = 10^{-12}$ W/m^2

<u>More noise sources</u>

Noise intensity

$$I_\Sigma = I_1 + I_2 + \ldots + I_n$$

$$I_0 \cdot 10^{L_\Sigma/10} = I_0 \cdot 10^{L_1/10} + \ldots + I_0 \cdot 10^{L_n/10}$$

Hence, noise level

$$L_\Sigma = 10 \log \sum_{i=1}^{n} 10^{L_i/10}$$

Examples of different noise levels:

- 160 dB – space rocket start (up to 200 dB)
- 150 dB – volcano explosion
- 140 dB – super jet, sirens
- 130 dB – industrial boiled, high pressure steam or gas draining
- 120 dB – rolling mill, industrial hummer, thunder, plane
- 110 dB – industrial work-shops, inside the orchestra
- 100 dB – near to train, cargo vehicles, funicular etc.
- 90 dB – noisy crossroads, pneumatic drill
- 80 dB – auto, motorbike, noisy street, orchestra from the auditorium
- 70 dB – static machines
- 60 dB – street
- 50 dB – normal speech, slow going car
- 40 dB – silent offices
- 30 dB – gardens, residence area
- 20 dB – whispering

- 0 dB – sound sensation limit and silence

Overhead lines noise

Source

- wind – broadband, turbulence, single frequency exceptionally
- „hum" – 100 Hz, magnetostriction, more at TRF
- corona
  - broadband, audible usually only during fog, rain, humidity
  - air ionization near conductor due to el. field
  - influenced also by the conductor surface quality

If discrete conductors charge Q (C/m) is known.
Intensity of electrical field near to conductor

$$E = \frac{Q}{2\pi\varepsilon_0 r} \quad (V/m)$$

In case of n-bundle each conductor has charge Q/n, then average intensity E:

$$E_1 = \frac{1}{n}\frac{Q}{2\pi\varepsilon_0 r} \quad (V/m)$$

If the bundle distance is a (m) then for maximum surface value E

$$E_{max} = E_1 \cdot \left(1 + \frac{(n-1)\cdot r}{a}\right) \quad (V/m)$$

Surface intensity E_{max} affects corona discharge. It causes noise near to overhead line.

Many methods for overhead line noise calculation exist.

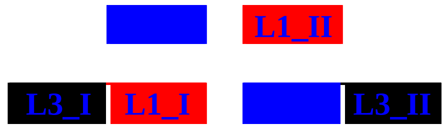
For example CIGRE:

$$L = 3{,}5 \cdot E_{max} + 12 \cdot r - 33\log D - 30 \quad (dB)$$

E_{max} (kV/cm), r(cm), D(m)

Typical OHL configuration	Basic support tower height N+0/(m)	Maximal surface electrical gradient[3)]	Weather type	Maximal audible noise level under OHL[4)], 1,8 m high	Audible noise level at the OHL protective zone border[5)], 1,8 m high
(-)	H (m)	E ($kV.cm^{-1}$)	(-)	L_A (dB)	L_B (dB)
1x400kV HORIZ Phase conductors 1x3x3AlFe450/52[1)] Ground wires 2xAlFe180/59	N+0 30,22 (m)	13,58	fair weather	18,64	12,25
			rainy weather	43,64	37,25
			heavy rain	47,14[N]	40,75[N]
2x400kV DANUBE Phase conductors 2x3x3AlFe450/52 Ground wires 2xAlFe180/59	N+0 41,6 (m)	14,92	fair weather	23,93	19,23
			rainy weather	48,93 [N]	44,23[N]
			heavy rain	52,43 [N]	47,73 [N]

1x220kV HORIZ Phase conductors 1x3x1AlFe450/52 Ground wires 2xAlFe180/59	N+0 25,0 (m)	15,40	fair weather	22,01	16,10
			rainy weather	47,01[N]	41,10[N]
			heavy rain	50,51[N,D]	44,60[N]
1x220kV HORIZ Phase conductors 1x3AlFe350/59 Ground wires 2xAlFe180/59	N+0 25,0 (m)	16,21	fair weather	23,97	18,07
			rainy weather	48,97[N]	43,07[N]
			heavy rain	52,47[N,D]	46,57[N]
2x220kV DANUBE Phase conductors 2x3x1AlFe 350/59 Ground wires 1xAlFe 180/59	N+0 38,2 (m)	17,09	fair weather	28,52	23,85
			rainy weather	53,52 [N,D]	48,85 [N]
			heavy rain	57,02 [N,D]	52,35 [N,D]
2x220kV DANUBE Phase conductors 2x3x2AlFe 350/59 Ground wires 1xAlFe 180/59	N+0 38,2 (m)	12,98	fair weather	13,35	8,87
			rainy weather	38.35	33,87
			heavy rain	41,85[N]	37,37



2x400 kV OHL DANUBE

I. CIRCUIT 2x400 kV OHL DANUBE

II. CIRCUIT 2x400 kV OHL DANUBE

		^{a}L2=12,72 $(kV.cm^{-1})$	^{b}L2=12,74 $(kV.cm^{-1})$		^{a}L1=12,73 $(kV.cm^{-1})$	^{b}L1=12,71 $(kV.cm^{-1})$		
		^{c}L2=12,92 $(kV.cm^{-1})$			^{c}L1=12,92 $(kV.cm^{-1})$			
^{a}L3=14,41 $(kV.cm^{-1})$	**^{b}L3=14,92 $(kV.cm^{-1})$**	^{a}L1=14,82 $(kV.cm^{-1})$	^{b}L1=14,39 $(kV.cm^{-1})$		^{a}L2=14,39 $(kV.cm^{-1})$	^{b}L2=14,81 $(kV.cm^{-1})$	^{a}L3=14,91 $(kV.cm^{-1})$	^{b}L3=14,41 $(kV.cm^{-1})$
^{c}L3=14,52 $(kV.cm^{-1})$		^{c}L1c=14,50 $(kV.cm^{-1})$			^{c}L2=14,50 $(kV.cm^{-1})$		^{c}L3=14,52 $(kV.cm^{-1})$	

Note: L1, L2, L3 – 1st or 2nd system phases; a,b,c – partial wires of 3-bundles

E_p maxima on partial wires AlFe 450/52 of 3-bundles 2x400kV OHL DANUBE