ENVIRONMENTAL IMPACT OF OVERHEAD LINES

Impacts:

- Property of the land
- Esthetic (area view)
- Ecological (flora, fauna, water)
- Technical(EMC, disturbances)
- Health
  - electric 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 line conductors on both sides.

For conductors without isolation:

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 is researched during last 40 years.
Many studies (impact on molecular mechanisms, genetical changes, disease) – statistical problems, not clear results and conclusions (low correlation).

- el. field – causes charges and currents at surface.
- mag. field – is inductive el. field, circulating currents.
- field energy – absorbed by living matter.

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

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

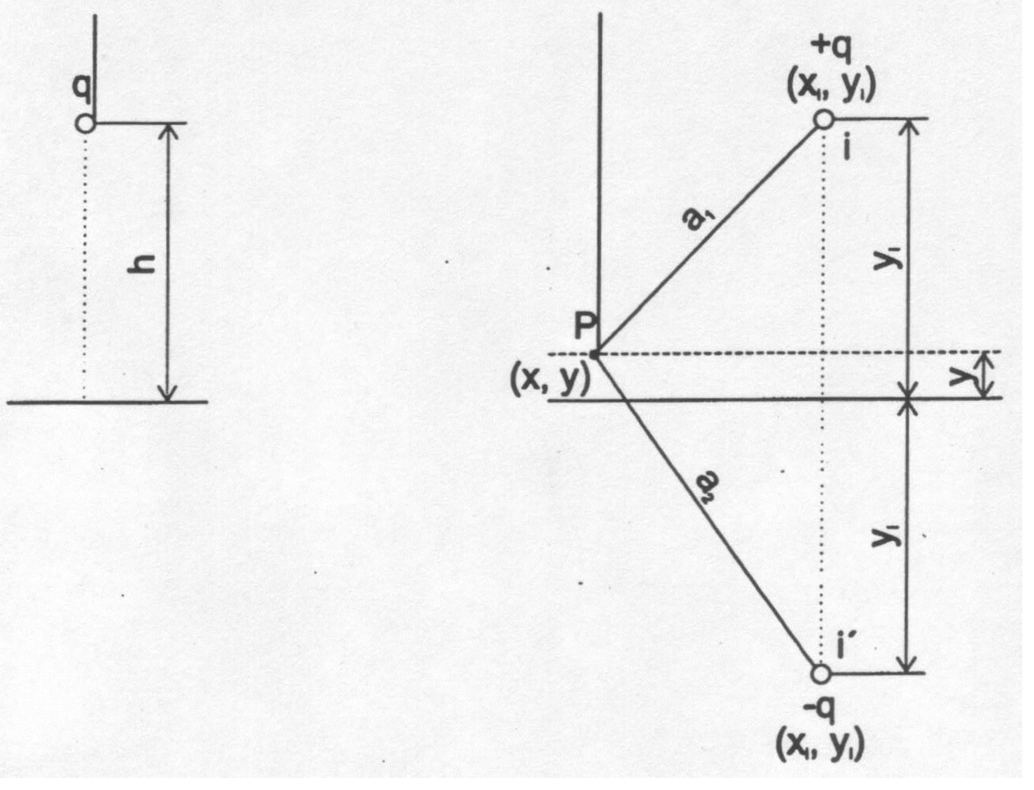
- 50 Hz limit values, employee
  - $E_{max} = 30 \ kV/m$
  - $B_{max} = 1600 \ \mu T$
- Directive ICNIRP (International Commission on Non-Ionizing Radiation Protection) from 1999, authorize WHO
  - 50 Hz,
  - public
    - $E_{max} = 5 \ kV/m$
    - $B_{max} = 100 \ \mu T$
  - employee
    - $E_{max}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

- ČSN 332040 (1993) – Protection against impact of electromagnetic field of 50 Hz in area of operational electrical system equipment.
  - Worker with electrotechnical qualification at control routes and working place: $E_{max} = 15\ kV/m$
  - $E_{max} = 15 \div 20\ kV/m \rightarrow$ 1,5hour/day
  - $E_{max} = 20 \div 25\ kV/m \rightarrow$ 0, 5hour/day
  - zone of power engineering equipment impact:
    - $E_{max} = 10\ kV/m$
    - $B_{max} = 500\ \mu T$
  - 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

Electric field calculation

Configuration:

- Line conductor with linear electric charge density q (C/m)
- ground is equipotential surface (U = 0) → mirror method



Potential at point $P_{(x,y)}$ above ground

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

ε_0 ..... permittivity of vacuum

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

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

If voltage is determined one conductor could be calculated:

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

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 at 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 electric field:

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

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

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

Voltage, charge and electric field are variable of time (phase shift).

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

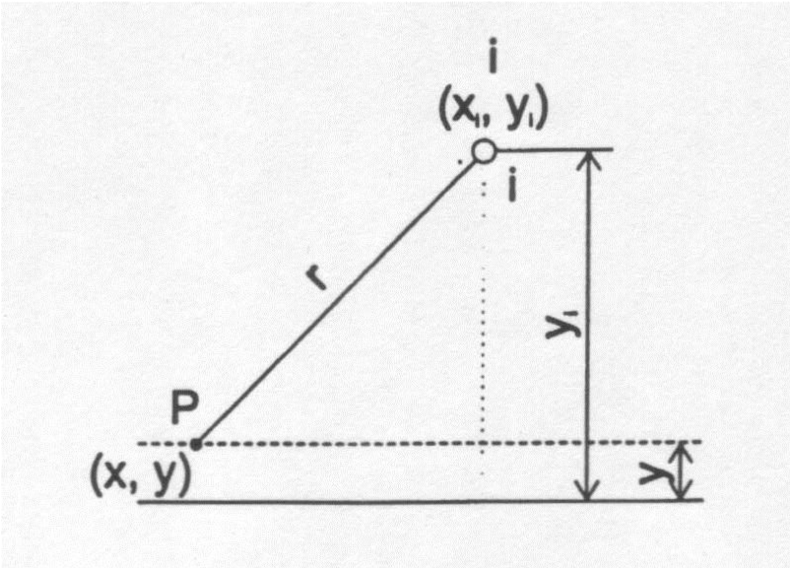
$$\left(\hat{Q}\right) = \left(\delta\right)^{-1}\left(\hat{U}\right)$$

Magnetic field calculation

Configuration:

- linear conductor is loaded by current i (A)
- currents in grounding wires are calculated using impedance matrix

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



Amperes law

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

Magnetic induction at point $P_{(x,y)}$ out of 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

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

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

Total values at point P

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

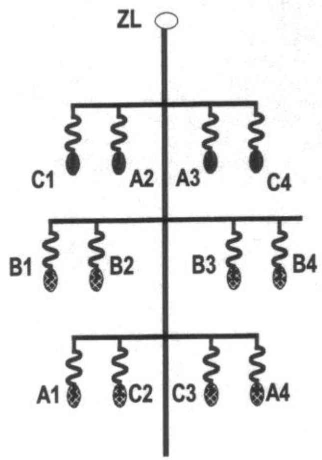
$$B_{\Sigma} = \sqrt{B_{x\Sigma}^{2} + B_{y\Sigma}^{2}}\,, \quad \vec{B}_{\Sigma} = B_{x\Sigma} + jB_{y\Sigma}$$

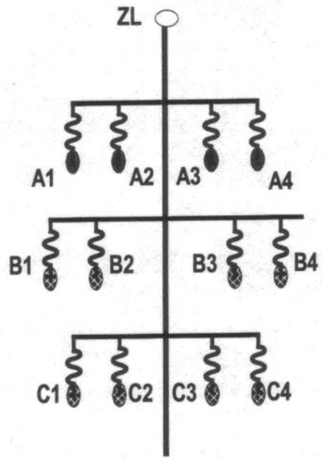
Current and magnetic field are time variable of time.

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

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

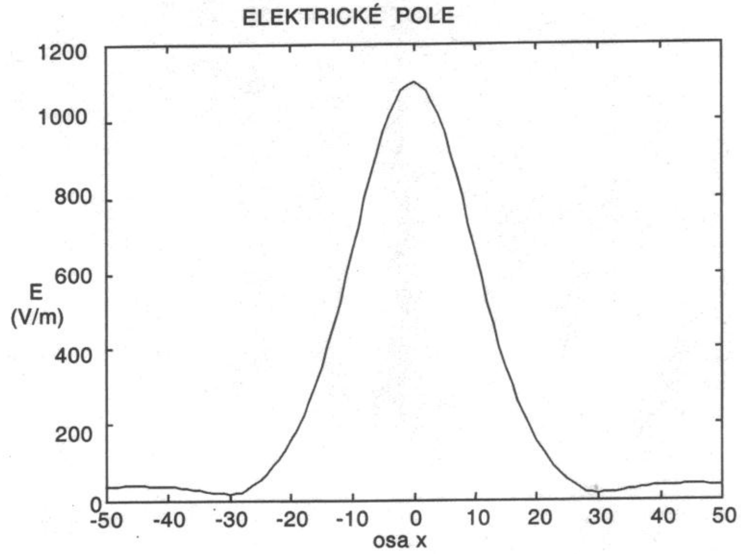
- Maximum value at given area (cross-section under the line)
- Optimization of the line minimizing field characteristics



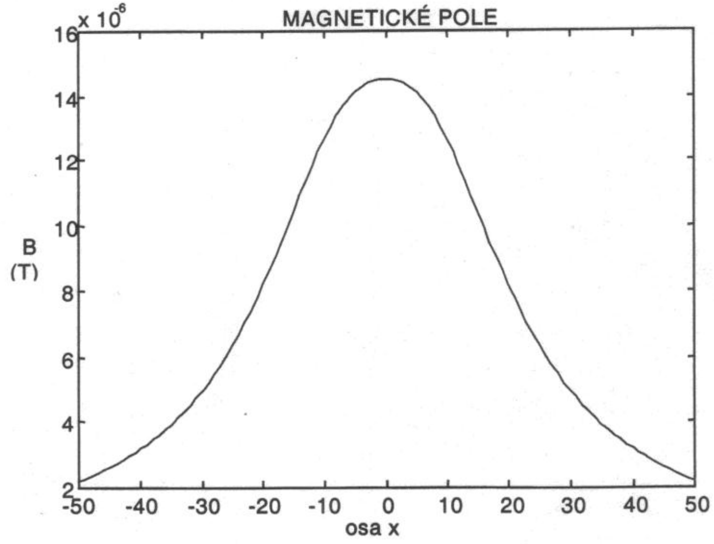


Vodič	Osa x (m)	Osa y (m)	Napětí (kV)
a	-7.2	25.2	22
b	-8.1	20.2	22
c	-7.8	15.2	22
a	-3.4	24.2	110
b	-4.3	19.2	110
c	-4.0	14.2	110
a	3.4	24.2	110
b	4.3	19.2	110
c	4.0	14.2	110
a	7.2	25.2	22
b	8.1	20.2	22
c	7.8	15.2	22
ZL	0	27.7	0

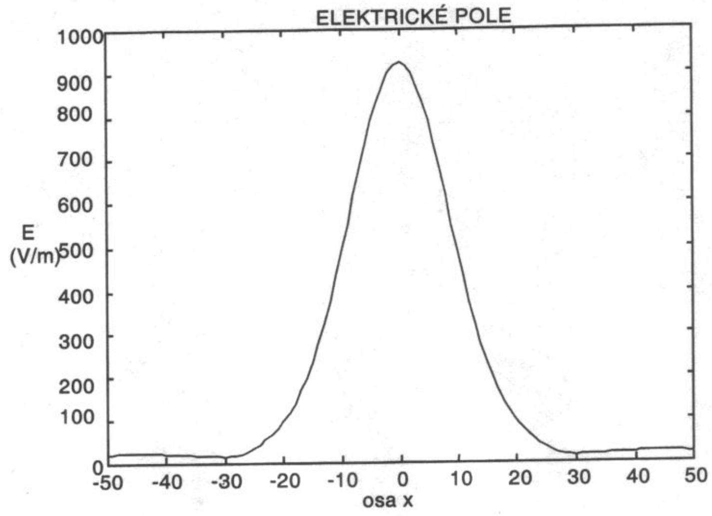
Vedení 2x22 kV (vnější, fáze a-b-c), 2x110 kV (vnitřní, fáze a-b-c)



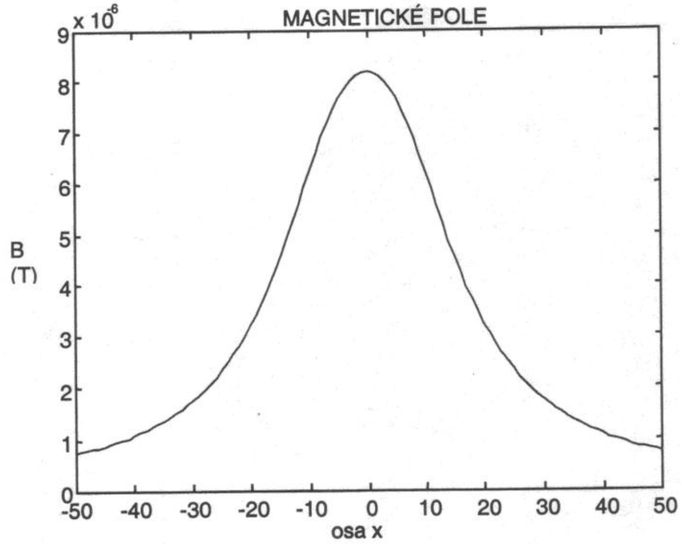
(110 kV)In=835 A
(22 kV)In=409 A

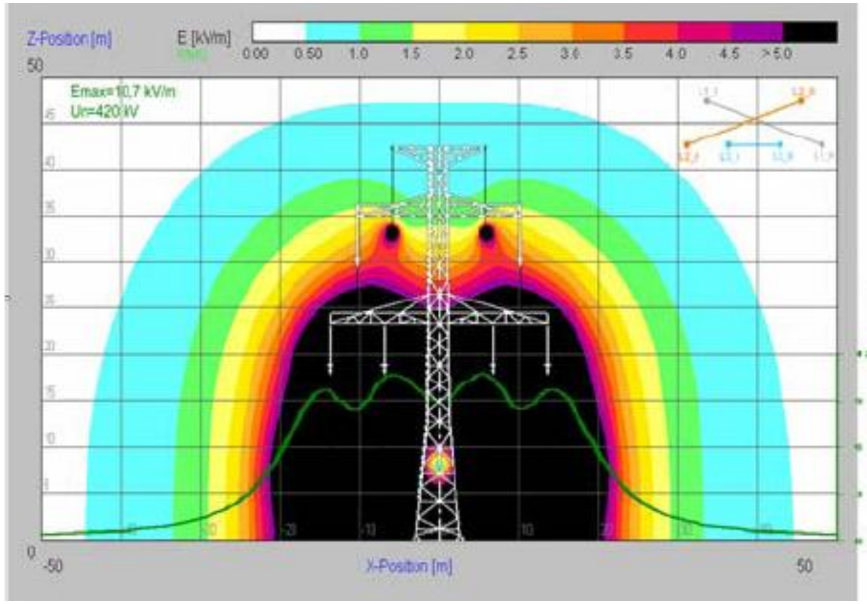


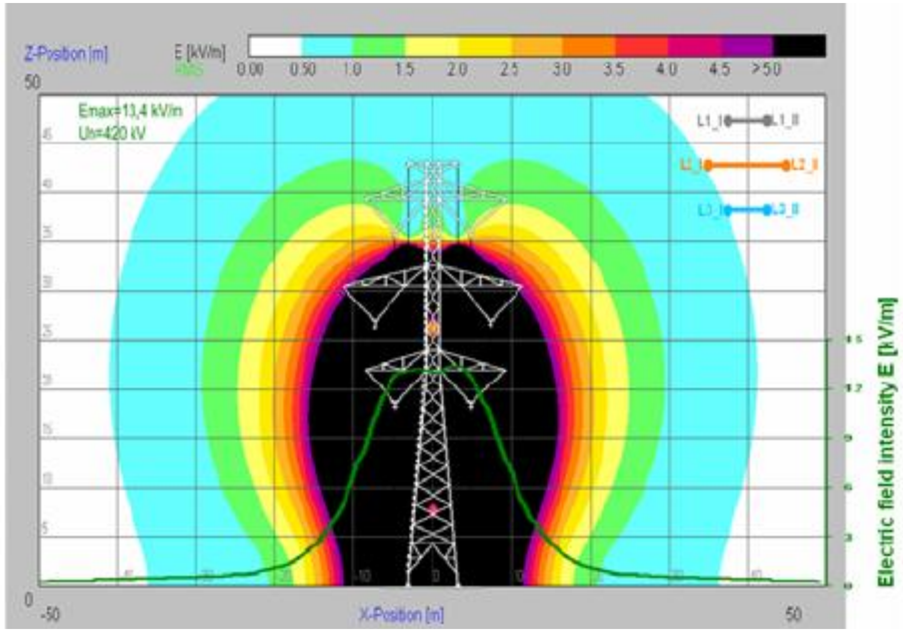
Vedení 2x22 kV (vnější, fáze c-b-a), 2x110 kV (vnitřní, fáze a-b-c)

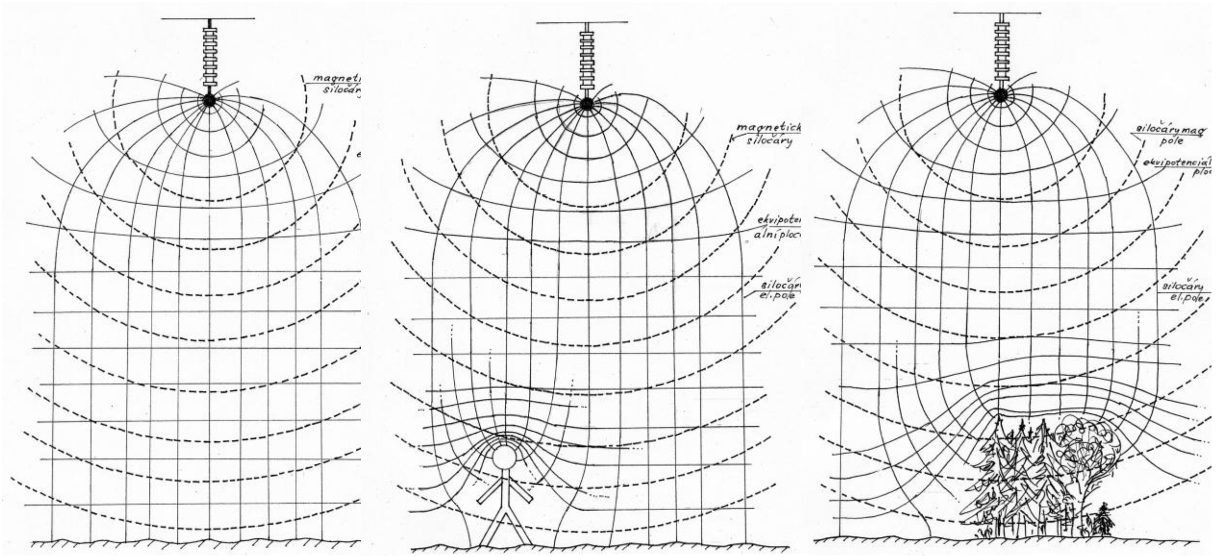


(110 kV)In=835 A
(22 kV)In=409 A




Z-Position [m]
E [kV/m]
RMS
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]
RMS
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
L1_I L1_II
X-Position [m]
Electric field intensity E [kV/m]



Electric field control:

- Increase distance from conductors to ground
- Voltage level decrease
- Number of bundle conductors and bundle distance
- Conductors distance (line compactness/size)
- Phase sequence
- Shielding wires under the line

Magnetic field control

- Increase distance from conductors to ground
- Current decrease
- Conductors distance (line compactness/size)
- Coupling conductors
- Phase sequence

Overhead line noise

Excessive noise – effects 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 premises:
    $L_{Aden} = 50$ dB, $L_{Anoc} = 40$ dB.

Noise level from source

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 effective value of acoustic pressure time function scaled to frequency correction curve (regards to human perception)

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

p_0 .... referential acoustic pressure

$p_0 = 2.10^{-5}$ Pa

Sound intensity I (sum for multi sources)

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

Generally I ~ 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 nose 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 – offices
- 30 dB – gardens, residence area
- 20 dB – whispering

- 0 dB – sound sensation limit and silence

Overhead lines noise

If discrete conductors charge Q (C/m) is known.

Intensity of electric field near to conductor

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

In case of n-bundle each conductor would have 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) than 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.

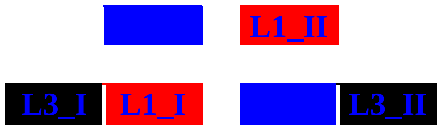
Many methods for overhead line noise calculation are existed.
For example CIGRE:

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

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