Journal of ELECTRICAL ENGINEERING, VOL. 57, NO. 1, 2006, 52–60

REVIEWS - LETTERS - REPORTS

EMISSION OF EMG FIELDS OF EXTREMELY LOW FREQUENCIES DUE TO HV LINES OF VARIOUS TYPES AND THE CURRENT ENERGY LEGISLATION IN CZECHIA AND SLOVAKIA

Eleonora Čermáková *

The article deals with experiments designed to determine emissions of electromagnetic fields of extremely low frequencies 50 Hz (ELF EMF) from HV lines of 22 kV constituted by bare lines (classic bare conductors), insulated lines (conductors with basic surface insulation), shielded lines (electrically shielded conductors) and underground lines (electrically shielded underground conductors). The ELF EMF emission is discussed in terms of protection zones established by the amended energy Czech law 458/2000 Sb. and the amended energy Slovak laws 70/1998 Z.z. and 656/2004 Z.z. in connection with the current Czech and Slovak laws on the protection of health against non-ionizing radiation 480/2000 Sb., and 271/2004 Z.z.

K e y w o r d s: legislation, measurements, extremely low frequency of electromagnetic fields, high-voltage lines, (HV lines), HV distribution conductors with basic insulation, HV distribution shielded conductors, HV distribution underground shielded conductors

1 NOMENCLATURE

$\mathbf{B}$	vector of magnetic flux density
$B(t)$	instantaneous value of magnetic flux density
B, B_{ef}	value of magnetic flux density, effective value of magnetic flux density
$B_{\text{RMS}}, B_{\text{PEAK}}$	value of RMS and PEAK magnetic flux density
$\mathbf{E}$	vector of electric field intensity
$E(t)$	instantaneous value of electric field intensity
E, E_{ef}	value of electric field intensity, value of effective electric field intensity
$E_{\text{int}}, E_{\text{ext}}$	value of the internal electric field intensity, value of the external electric field intensity
ELF, EMF	Extremely Low-Frequency of ElectroMagnetic Fields
$E_{\text{RMS}}, E_{\text{PEAK}}$	value of electric field intensity RMS and PEAK
$\mathbf{H}$	vector of magnetic field intensity
HV	high voltage
ICNIRP	International Commission of Non-ionizing Radiation Protection
J	current density
S	cross section
T	undulation period
f	frequency
h	height
r	radius
t	time
Γ	circumference
ε_∞	permittivity at infinite frequencies,
ε_{ext}	permittivity of external medium at static fields
ε_s	permittivity at static fields
μ	magnetic permeability
$\sigma, \sigma_{\text{int}}$	electrical conductivity, electrical conductivity of tissue
τ	time constant
$\Phi(\omega)$	magnetic flux

2 INTRODUCTION

The Czech energy law 458/2000Sb. has been five times amended and the last amendment 670/2004 concerns §46 [1] dealing with protection zones under HV and EHV distribution lines on account of new developing types of insulation for these conductors. The amended Slovak energy laws 70/1998 Z.z. §19 [2] and 656/2004 Z.z. §36 [3] (the last text becomes effective from 1 July 2007) also regulate protection zones under HV and EHV lines for the same reason. The protection zone for the purposes of this law is understood to be the space in immediate proximity to manufacturing and distributing facilities — HV and EHV distribution lines — designed to ensure their reliable operation and protection of life, health and personal property. The protection zones protect overhead lines, underground lines and electric stations.

The protection zone of overhead lines is delimited by vertical planes drawn by both sides of the line in horizontal distance measured perpendicularly to the line, the distance being different on each side in dependence on the type of HV and EHV lines. The distribution of high and extremely high voltages initially were made with bare

* Department of Physics, Faculty of Civil Engineering, Brno University of Technology, Czech Republic

Table 1. Protection zones for HV and EHV lines in Czechia and Slovakia

	Czechia 548/2000 46 Sb.	Slovakia 70/1998 Z.z.	Slovakia 656/2004 34 Z.Z. (1)
Voltage over 1 kV to 35 kV inclusively			
conductors without insulation	7 m	10 m/7 m (2)	10 m/7 m (2)
conductors with basic insulation	2 m	—	4 m* /2 m* (2)
suspension shielded cable lines	1 m	2 m	1 m*
underground shielded lines	1 m (3)	1 m	1 m
Voltage over 35 kV to 110 kV inclusively			
conductors without insulation	12 m	15 m	15 m
conductors with basic insulation	5 m	–	–
suspension shielded cable lines 110 kV	2 m	l2 m	2 m
underground shielded lines	1 m (3)	1 m	1 m
Voltage over 110 kV to 220 kV inclusively			
conductors without insulation	15 m	20 m	20 m
underground shielded lines	3 m (3)	3 m	3 m
Voltage over 220 kV to 400 kV inclusively			
conductors without insulation	20 m	25 m	25 m
Voltage over 400 kV			
conductors without insulation	30 m	35 m	35 m

(1) The last state of the text becomes effective from 1 July 2007; (2) In continuous forest isles; (3) On either side of marginal cable

* The size of protection zones is defined from the marginal conductor of HV and EHV distribution. From the central conductor, the size of the protection zone will be determined in dependence on the authorized distance of distribution conductors. For the 22 kV lines, the distance of the bare conductors should not be less than 1 m; for insulated conductors, this distance is reduced to 60 cm. Hence follows that *eg* for the lines of 22 kV in case of bare wires, from the central conductor the protection zone is at least $7+1=8$ m (Czechia), $10+1=11$ m or, for continuous forest isles, $7+1=8$ m (Slovakia). For insulated conductors, the total size of protection zones is 2.60 m (Czechia) and from 1.7.2007 4.60 m, or for continuous forest isles 2.60 m (Slovakia), With suspension cable lines, the protection zone is *l* m for Czechia and 2 m and from 1.7.2007 — 1 m for Slovakia.

The protection zone for underground lines for electric systems under 110 kV inclusive, control and measuring lines, and safety facilities is 1 m and for systems over 110 kV, 3 m at either side of the marginal cable — this is true, for the Czech and Slovak Republics.

Table 2. Induced current density (J/Am^{-2})

Frequency f/Hz	Personnel J/Am^{-2}	Population J/Am^{-2}
4–1000	0.01	0.002

Table 3. The reference values of electric field intensity and magnetic flux density

Frequency f/Hz	electric field intensity E/Vm^{-1}		magnetic flux density $B/\mathrm{T_{tesla}}$	
	personnel	population	personnel	population
50	10 000	5 000	5×10^{-4}	1×10^{-4}

lines without shielding and insulation. To provide for reliable operation of HV and EHV distributions and reliable protection of life, health and property in immediate proximity to these power distributions, the protection zones were sufficiently, broad and took up broad forest aisles and broad bands of building lots where building operations were not possible or required exceptional authorization. Constructions under HV line are not banned in every state, *eg* in USA building operations are allowed even directly under power distribution lines. In the 80's of the last century, this brought about polemics and medical studies of potential effects of ELF EMF on human population. [10] brings a study of effects of ELF EMF on infantile population which shows that there exists a weak probability of leukaemia already with an exposure of 10^{-6} T. For adult population, no carcinogenesis was proved with exposures through magnetic fields of this intensity. There were rather unspecific types of diseases, higher fatigue, changes in the blood image, insufficient concentration, reduced immunity and the like [9].

The EU, Czechia and Slovakia legislatively treated exposures of population through ELF EMF at the beginning of the present century [4–8]. Consequently, the EU states having no protection zones for HV and EHV lines will have to establish them.

Yet in the meantime, there is a further development of energy conductors and insulated conductors and shielded overhead and shielded underground cable conductors are being introduced into practice. Experimental results indicate that there will be highly different ELF EMF emissions for the types of energetic distributions.

Table 1 compares the sizes of protection zones in Czechia and Slovakia.

As mentioned above, the legislation establishing protection zones for HV and EHV lines appreciably preceded the legislation concerned with protection against non-ionizing radiation with frequencies of 50 Hz. For this frequency, the maximum admissible values of induced current density in the human body and the reference values of the magnetic flux density and intensity of electric field are given in tables 2 and 3 (extract from Czech legislation 480/2000 Sb.) The Slovak legislation is similar, except that it does not consider the maximum admissible values of the current density induced in the human body and considers the reference values of magnetic flux density and intensity of electric field as maximum admissible values. In this way it essentially makes its legislation concerned with protection against non-ionizing radiation more rigorous.

It should be emphasised that prior to legislation concerned with the protection of human organisms against non-ionizing radiation — in our case covering frequencies of 50 Hz — the protection zones for energy distributions were designed to provide access to these distributions with regard to repairs and protection against mechanical destructions caused by falling trees, branches etc. New, with legislation protecting human health against non-ionizing radiation it is necessary to consider also biological protection zones. It is in fact suitable to verify whether the size of technical protection zones satisfies also from the standpoint of biological protection of the human organism.

An extract from the Czech legislation (480/2000Sb.), for the frequency of 50 Hz, is given in Tables 2 and 3.

In Table 3. the Ordinance 480/2000 Sb. contains limiting values for the frequency of 50 Hz, *ie* reference values (The reference values E and B are effective values $E_{\text{ef}}, B_{\text{ef}}$ (designated more $E_{\text{RMS}}, B_{\text{RMS}}$) which, when reached, do not yet danger any exposed person. These values were established on the basis of many medical studies [9, 10]. With values in excess of these reference values, the induced current density in the conductive human body (see Eq. 1–7) must be reckoned with. Various parts and organs of the human body exhibit different electric conductivities [11]. Calculations of induced current densities are usually based on an average electric conductivity and take into account the different induced current densities in the human torso and limbs which have a low electric conductivity. Tables 2 and 3 give reference values and maximum admissible current densities for professionals and population, the values for professionals being higher than those for population. This difference is accounted for by the duty of professionals to regularly undergo medical examinations, by contrast to normal population, and the persons are representative for the productive age. The population included persons of every age (children, adults, old men) and also of different health. 7 The legislative sphere concerning exposures of human organisms to non-ionizing radiations of extremely low frequencies is living, topical and variable.

3 PHYSICAL FORMULATION OF THE ELF EMF EFFECTS ON HUMAN ORGANISM

The reference levels and maximum admissible current densities in the mentioned legislations, ordinances and recommendations are based on medical research. Still, the effects of low-frequency electromagnetic fields can be derived also by theoretical relations concerning the responses of an electrically conductive human body to the electric and magnetic components of ELF fields. The dominant effects of ELF EM fields on an electrically conductive human body are those of the alternating magnetic component. It passes nearly unchanged and unabsorbed through the human body and induces small electrical currents which cannot change the balance and function of vital organs. The induced current densities in human bodies will be derived as follows [9].

Consider a uniform magnetic field $\mathbf{H}$ in which a spherical object is immersed. This sphere presents, in a plane perpendicular to $\mathbf{H}$, a circular cross section. The sphere is uniform with conductivity σ, relative magnetic permeability μ and radius r.

There are analytical expressions for current densities induced by an external magnetic field in a conductive tissue of spherical form.

The magnetic flux density $\mathbf{B}$ can be written as

$$\mathbf{B}(\omega) = \mu \mathbf{H}(\omega) \tag{1}$$

and the magnetic flux $\Phi(\omega)$ in the cross section S of the object is

$$\Phi(\omega) = \iint_S \mathbf{B}(\omega) \cdot \mathrm{d}\mathbf{S} \,. \tag{2}$$

If the dimensions of the cross section are smaller than the wavelength under study, we can consider that the magnetic flux density $\mathbf{B}$ is constant over S. In that case, the voltage induced along the circumference of the object, which is given by the Lenz law, can be written as

$$e(\omega) = -\omega\Phi(\omega) = -\omega\mu S H(\omega) \,. \tag{3}$$

The average value of induced electric field $\mathbf{E}$ on the circumference Γ of the cross section is given by

$$|\mathbf{E}(\omega)| = \frac{e(\omega)}{\Gamma} = \omega\mu H(\omega)\frac{S}{\Gamma} \tag{4}$$

and the value of current density J is deduced through Ohm's law

$$J(\omega) = \sigma E(\omega) = \sigma\omega\mu H(\omega)\frac{S}{\Gamma} \,. \tag{5}$$

For the circular cross-section the surface and the circumference are respectively

$$S = \pi r^2 \text{ and } \Gamma = 2\pi r \text{ and } J(\omega) = \sigma\omega\mu\frac{r}{2}H(\omega) \,. \tag{6}$$

We can also write the modulus of J in the form

$$|J(\omega)| = |K(\omega)|\frac{r}{2} \text{ and } |K(\omega)| = \sigma\omega\mu|H(\omega)|\,. \qquad (7)$$

Thus, the induced current density is dependent on the above factors. Formula (7) will be used whenever the reference values of Table 3 are exceeded. The result is usually an approximation because an average electric conductivity of human tissues and a definite (in our case spherical) model of the human body with radius r are applied. Practical calculations consider the part of human organism with maximum electrical conductivity, *ie* the area of abdominal cavity with radii 15–20 cm). The tabular electric conductivity of some organs is specified for an adult man [11].

The electric ELF EMF component mostly charges the surface of human body and the interaction with the human body can be explained in the following way.

The frequency dependence of the body properties is accounted for by changes in the human tissue permittivity.

$$\varepsilon = \varepsilon_\infty + (\varepsilon_S - \varepsilon_\infty)(1 + i\omega\tau)^{-1}, \qquad (8)$$

where ε_∞ refers to the permittivity at infinite frequencies, ε_S refers to the permittivity at static fields, $\omega = 2\pi f$, where f is the frequency of ELF electric fields. The time constant τ depends on the physical process involved.

In [9] there is also a discussion of the experimental fact that the external electric field (electric component of ELF ELM fields) enters the body always perpendicularly to its surface and the value of the electric component inside the body E_{int} is always lower by several orders of magnitude than the entering external component E_{ext}, and that in the ratio

$$E_{\text{int}} E_{\text{ext}}^{-1} \approx \omega\varepsilon_{\text{ext}}\sigma_{\text{int}}^{-1}\,. \qquad (9)$$

This result is derived from Maxwell's equations, from the boundary conditions for the vertical component of the electric field at the interface of external medium (air) and internal medium (electrically conductive tissue) where ε_{ext} is the permittivity of external medium, *ie* air or vacuum (in this case $\varepsilon_{\text{ext}} = \varepsilon_0$) and σ_{int} is the electrical conductivity of tissue.

4 EXPERIMENT

Although the amended energy laws refine upon the size of protection zones, their authors did not establish the size of zones with regard to protection of *professionals or current population* against exposures to low-frequency electromagnetic fields. The following experimental study is designed to show whether the protection zones under high-voltage lines are big enough to comply with legislative criteria concerned with protection against nonionizing radiation.

4.1 Measuring equipment

To detect extremely low-frequency electromagnetic fields (ELF EMF) under high-voltage lines, a professionally manufactured calibrated device of high quality was used which allows to separately measure, selectively or in broad band, the value of magnetic flux density and the value of electric fields intensity. The device evaluates the effective and maximum values of both components of electromagnetic fields, measures separately the magnetic component within 5 nT–10 mT, and the electric component from 0.1 V/m up to 100 kV/m. The magnetic and the electric sensors measure with 5 % accuracy. The display of the device allows to read the vector of the magnetic flux density (or intensity of electric field) as well as the components x, y and z of the values being measured. The easily accessible menu is designed to select the measurement range and also to set the frequency filter of the signal to detect. The device allows to select 11 different narrow-band filters, namely 16.7 Hz, 33.3 Hz, 50 Hz, 60 Hz, 100 Hz and the like, and provides for 4 adjustments of broad-band filters 5 Hz–2 kHz, 30 Hz–2 kHz, 5 Hz–30 kHz, 30 Hz–30 kHz. In our case, the broad-band filter 5 Hz–2 kHz was used in case the values detected under the HV line being measured involve subharmonic or higher harmonic frequencies.

The device is made up of two main parts, namely of a magnetometer and a separate cubic probe which operates as an independent analyzer of electric field intensity. The magnetic probe is part of a digital device, the electric probe is external and can be connected to the body of the device by optical cables. The probes contain an in-built processor and a frequency counter. The in-built memory and timer allow to automatically score the data measured inclusive of time data. The magnetic and electric probes measure isotropically, *ie* they detect the field components in three axes x, y, z, which makes possible to determine the main direction of the field.

Detected values can be scanned manually or automatically. They can be optically transferred to a computer and ultimately processed graphically.

The device allows two ways of detection:

RMS detection — equivalent magnetic flux density is scanned which was calculated from effective values of the probe. The display shows the effective magnetic flux density B_{ef} and electric field intensity E_{ef} which are elements considered in reference values.

$$B_{\text{RMS}} = \sqrt{\frac{1}{N}\Big(\sum_{n=1}^{N} B_{Xn}^2 + \sum_{n=1}^{N} B_{Yn}^2 + \sum_{n=1}^{N} B_{Zn}^2\Big)}\,;$$
$$E_{\text{RMS}} = \sqrt{\frac{1}{N}\Big(\sum_{n=1}^{N} E_{Xn}^2 + \sum_{n=1}^{N} E_{Yn}^2 + \sum_{n=1}^{N} E_{Zn}^2\Big)}\,. \qquad (10)$$

PEAK detection — the illustration is the equivalent magnetic flux density calculated from the maximum voltage

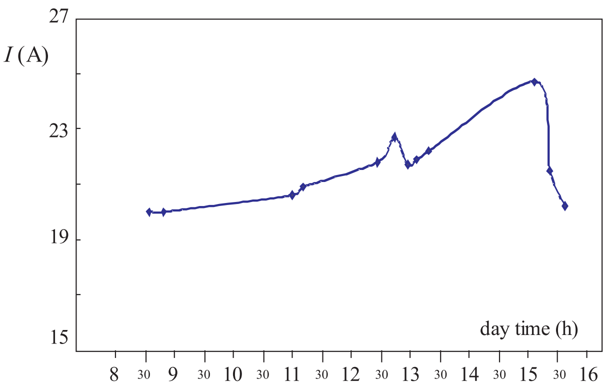

Fig. 1. Power off-take from HV line in measuring electric field intensity. The chronological course of the power off-take is not constant.

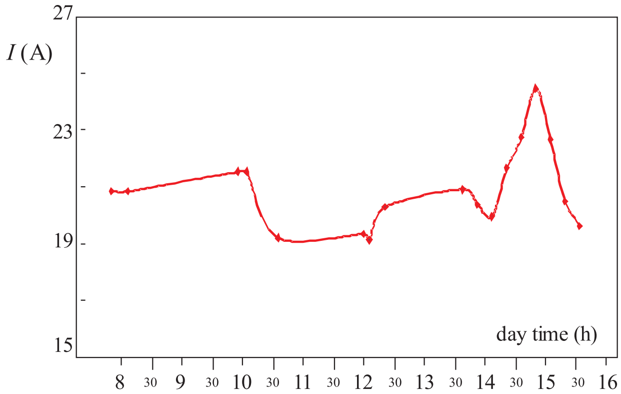

Fig. 2. Power off-take from HV line in measuring magnetic flux density. The chronological course of the power off-take is not constant.

of the probe. $B_{\mathrm{PEAK}} = \mathrm{MAX}(B_{1\mathrm{PEAK}}, \dots, B_{N\mathrm{PEAK}})$, the same for the E_{MAX}

$$B_{\mathrm{PEAK}1\dots N} = \sqrt{B^2_{X1\dots N} + B^2_{Y1\dots N} + B^2_{Z1\dots N}}\,, \qquad E_{\mathrm{PEAK}1\dots N} = \sqrt{E^2_{X1\dots N} + E^2_{Y1\dots N} + E^2_{Z1\dots N}}\,, \tag{11}$$

4.2 Course of the experiment

The measurement of the low-frequency electromagnetic field emitted by a high-voltage line of 22 kV using various types of electric conductors was made under relatively good meteorological conditions (sunny weather, low relative humidity, temperature of 10–15 °C). Emission of low-frequency electromagnetic field was measured in both the electric and magnetic components. The results of the measurement concern the following types of electric conductors:

1. bare conductors (classic conductors),
2. conductors with basic insulation (the conductors with basic insulation make possible smaller mutual distances between conductors, impede short circuits due to accidental contacts and allow smaller occupation of agricultural or forest areas),
3. shielded overhead conductors (electrically shielded conductors with electric distribution evident from Fig. 11),
4. underground conductors (electrically shielded conductors laid under ground).

4.2.1 Measurements of current in HV conductors of 22 kV

The power off-take in the HV line of 22 kV was measured by the professionally manufactured device Circusor operating on the principle of detection of infrared radiation. The amount of the off-take was detected in not very regular intervals.

In Figures 1 and 2 the axis y shows the power (current) off-take in a HV line of 22 kV. The diagrams make evident the irregular power off-take as a function of time (axis x). Figure 1 shows the off-take in measuring the electric fields intensity — Figure 2 illustrates power off-take in measuring the magnetic flux density. Owing to long-term measurement, not all time dependences of power off-take from the power mains were recorded.

4.2.2 Measurement of emission of low-frequency electromagnetic HV field of 22 kV

4.2.2a Intensity of electric fields emitted by bare, insulated, shielded underground and shielded overhead lines of 22 kV.

Figure 3 shows the electric intensity emitted by HV lines constituted by bare conductors. The measurement was made on a lot situated under a HV line in a point where the height of the conductors was 10 m above the ground. It was made in regular steps of 1 m, with point 0 located on a vertical line under the centre of the HV line. The other points of measurement were on a line passing perpendicular to the direction of the HV line and in only one direction, under the assumption of symmetrical shape of ELF EMF emission to both sides of the HV line. In the same way measurements were made also under HV lines with insulated conductors, overhead and underground shielded HV lines of 22 kV. Measurements under HV lines with bare conductors were repeated for seven different heights between 0.7 m–5.4 m.

Figure 3 makes evident a growth of the electric field intensity with an increasing height above the ground in the direction to the HV line conductors. A maximum intensity was found at a height of 5.4 m above the ground, 4.6 m away from the HV line conductors — nearly 8 kV/m. This diagram allows to determine how the protection zones correspond to the limiting values in legislation concerned with exposures to non-ionizing radiation at a frequency of 50 Hz.

Let us imagine a building the peripheral wall of which stands on the boundary of the protection zone (see Table 1), *ie* 7.0 m away from the marginal bare conductor of HV power distribution or 8.5 m away from the central conductor of a 22 kV line according to the Czech law 458/2000 Sb.; or, outside of continuous forest covers, 10 m away from the marginal bare conductor or 11.5 m

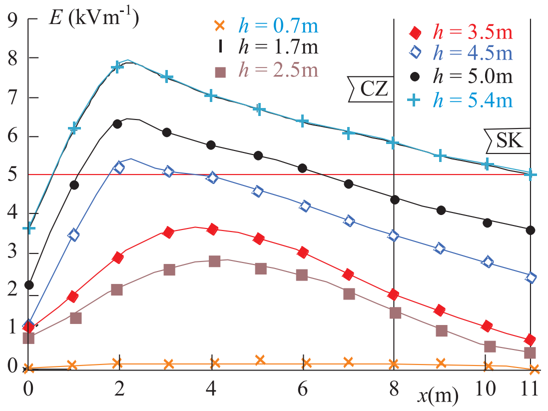

Fig. 3. Electric field intensity emitted by HV line of bare conductors.

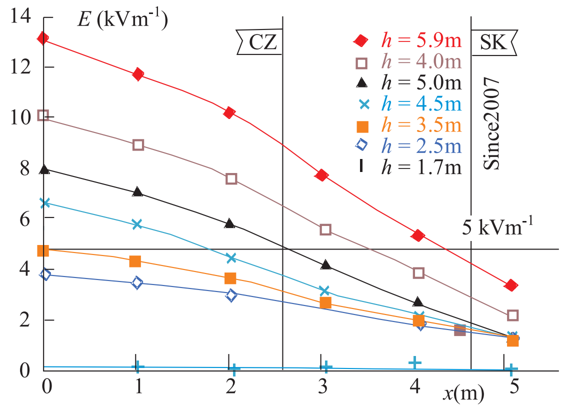

Fig. 4. Intensity of electric field emitted by a HV line of insulated conductors (conductors with basic insulation).

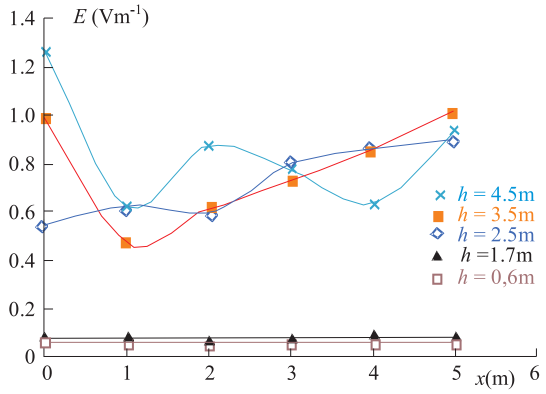

Fig. 5. Intensity of electric field emitted by a HV line of shielded overhead conductors. (Distribution with electrically shielded conductors, see Fig. 11).

from the central conductor of 22 kV line according to the Slovak laws 70/1998 and 656/2004. Then in the perpendicular distance to the HV conductor and at a height of 5.2 m and more, *ie* ±4.8 m from the HV line in Czechia and 5.4 m and more, *ie* ±4.6 m from the HV line in Slovakia, the peripheral walls will be exposed to an E component exceeding the reference values of 5 kV/m for current population in Czechia and the maximum admissible E component in Slovakia. It means that on balconies and at windows it would be possible to detect the above-mentioned electric components of ELF EMF for the given heights. Much lower values of E — two or three orders less — would be detectable in the interior of the building as a result of the high reflexivity of the E component. This problem (high values of the component E) will be resolved, *eg* by overhead or underground cable shielded lines.

A very low emission of the electric component is evident from the graph. The irregular curve shape is given by the non-constant power off-take from the distribution net — see Fig. 1 and the shielding of the E component due to the electric shielding of the energy distribution.

Interesting results are provided by measured emissions of electric field intensity due to insulated conductors of HV lines. See Fig. 4. The measurements were made under a HV line the conductors of which were reaching a height of 9 m above the ground. Under the centre of the HV line, at the maximum height of the measurement (5.9 m above ground, *ie* 3.1 m under the HV line) the intensity of electric field was found to be 13 kV/m. Increasing distances perpendicular to the HV line diminish emissions and on the boundary of the protection zone or 2.6 m away from the central conductor (Czech law 458/2000 Sb.), emission of insulated lines reaches 5 kV/m, which is the reference value of the Czech law 480/2000 Sb. concerned with protection of current population against non-ionizing radiation at a height of 5 m above ground (4 m under HV lines). It means that heights ±4 m from such lines on the boundary of protection zone will bring higher than reference values.

The Slovak law 70/1998 in fact has no protection zone for this type of HV lines because protection zones — 4 m from the central conductor 4.6 m — and 2 m from the central conductor for continuous forest covers will not be introduced until the year 2007 (656/2004 Z.z.). The protection zone 4.6 m and 5 kV/m, the maximum admissible values under the Slovak law 271/2004 Z.z. give, by means of extrapolation, a height of about 6.1 m under the line being measured or 2.9 m under HV lines. At this height of ±2.9 m emission of electric field intensity achieves the same values as or higher than the maximum admissible values of the Slovak laws. The results of measurements bring heights which expose building walls or people in windows, on balconies on the boundary of protection zone to ELF EMF values superior to the limits. The values inside the building will be substantially lower.

Figure 5 illustrates the measurements of the electric field intensity emitted by shielded overhead HV line of 22 kV. (See Fig. 11) The height of the shielded conductors was 8 m. The intensity of the component E was measured up to a height of 4.5 m. At this maximum height of 3.5 m under the HV line and on the boundary of protection zone the intensity of electric field is 3 orders less than the emission of the classical bare lines and is also 3 orders below the reference values stated in the Czech law 480/2000 Sb. and the maximum admissible Slovak values of the law 271/2004 Z.z. (see Table 1 —

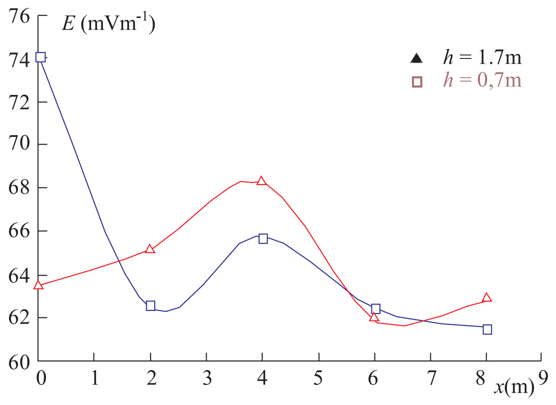

Fig. 6. Intensity of electric field E emitted by a shielded underground HV line of 22 kV/50 Hz for the heights 0.7 m and 1.7 m above ground. The detected size of electric field intensity is negligible. The irregular course is given by non constant power off - take from the distribution net — see Fig. 1 — the shielding of the E component through the electric shielding of the energy distribution, and by absorption in the soil.

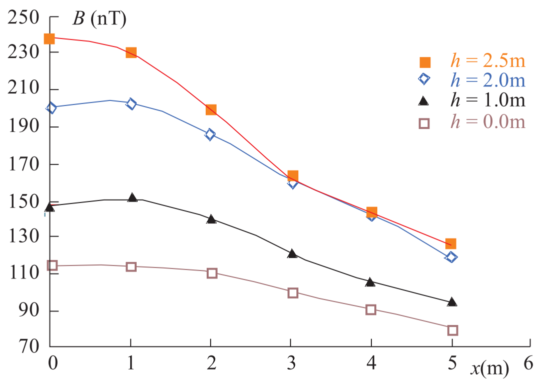

Fig. 7. Magnetic flux density due to classical bar of 22 kV HV line

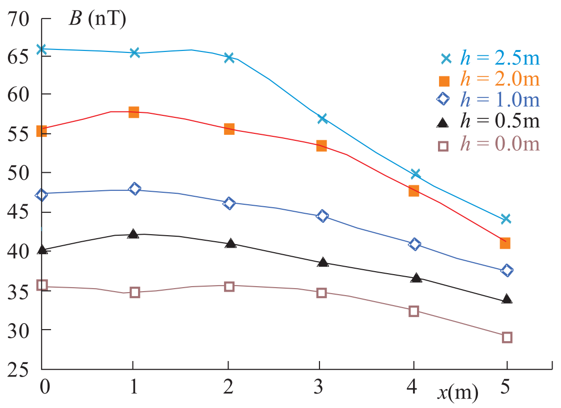

Fig. 8. Magnetic flux density due to insulated HV lines of 22 kV. The irregular course is given by non-constant power off-take from the distribution net (see Fig. 2).

1 m from 458/2000 Sb.; 1 m from 656/2004 Z.z. applicable only from the year 2007; 2 m from 70/1998 Z.z., which is an unnecessarily big distance — evident from values plotted in Fig. 5. The irregularities in the component E of overhead shielded lines are due to different power off-takes from HV lines (see Fig. 2) and also to very small electric field intensity, mostly amounting to $x \times 10^{-1}$ V/m which may contain an sensibility of measurement. It is obvious from the values measured that on the boundary of protection zone for this line the emission of electric component reaches limiting values for no height under or above the HV lines.

Figure 6 presents the measured emissions of the low-frequency electric field intensity due to shielded underground HV line of 22 kV, for the heights 0.7 m and 1.7 m above ground. Intensity emitted by the underground line is negligible and is 5 orders below the reference values stated in the Czech law 480/2000 Sb. and also 5 orders below the maximum admissible values under the law 271/2004 Z.z.. As a result of reflexion and absorption of component E in the shielding space of the cable and in the underground space — at least 1 m below ground (clay, stones, and the like) — the electric ELF EMF electric component will practically not get to the ground. The values detected are of the order of 10^{-2} V/m and are highly influenced by sensitivity of the detector in use.

4.2.2b Magnetic flux density emitted by classical bare, insulated, shielded overhead and shielded underground power distribution of 22 kV.

The magnetic flux density emitted by a classical bars line of 22 kV is plotted in Fig. 7. The height of the bare power lines was 10 m above the ground. Magnetic component was measured at the heights 0, 1, 2 and 2.5 m above the ground, *ie* 10, 9, 8 and 7.5 m away from the HV lines, up to the perpendicular distance of up to 5 m from the central HV line. The magnetic flux density detected varied within an interval 7×10^{-8} T to 2.4×10^{-7} T. The reference magnetic flux densities for current population and for 50 Hz under the Czech law 480/2000 Sb. and the maximum admissible values under the Slovak law 271/2004 Z.z. are 3 orders higher (10^{-4} T).

Detection of the magnetic flux density for HV distribution of 22 kV using conductors with basic insulation (see Fig. 8) measurements was made up to the height of 2.5 m and brought the following results. The magnetic flux density detected ranged within the interval 3.5×10^{-8} T–6.5×10^{-8} T. A similar magnetic flux density is that of the classical bare lines, with insulate lines the detected ELF EMF components B are about 1/2 order less than with lines of bare conductors. Thus it can be said that magnetic flux density is almost not shielded by insulated lines.

Figure 9 shows magnetic flux density emitted by shielded overhead power lines of 22 kV. The same as for the preceding measurements, magnetic flux density was measured up to the height of 2.5 m. The magnetic flux density ranges within the interval (10^{-9}–10^{-8}) T. The extreme value of magnetic flux density measured at the height of 2.5 m is caused by irregularities of the off-take from mains and, in the region of 10^{-9} T, by inaccuracies in the detection of the component B. Compared with the

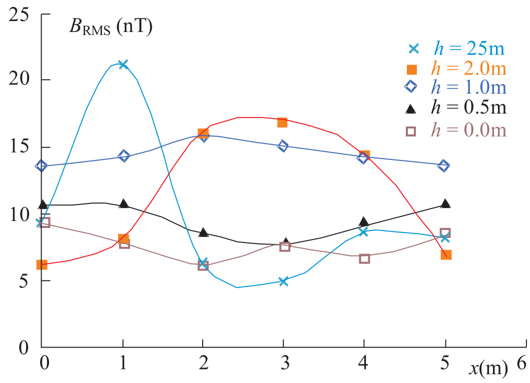

Fig. 9. Magnetic flux density due to shielded overhead lines of 22 kV. The detected size of magnetic induction is negligible. The irregular course is given by non-constant power off-take from the distribution net see Fig. 2 — and the shielding of the component B due to the electric shielding of the energy distribution.

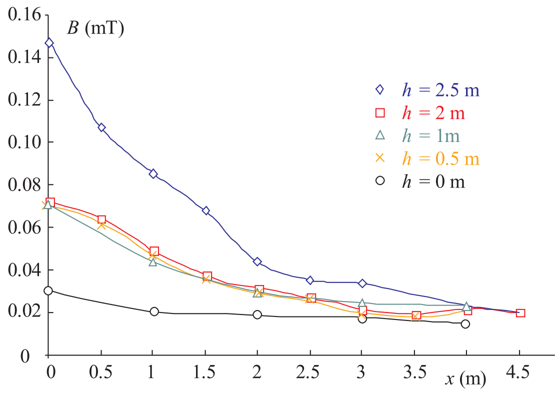

Fig. 10. Magnetic flux density emitted by a shielded underground line of 22 kV for heights 0, 1, 2, and 2.5 m above ground. The detected size of magnetic induction is is higher than results presented in Fig.7 to Fig.9. The irregular course is given by non-constant power off-take from the distribution net see Fig. 2 — and the shielding of the B component due to the electric shielding of the energy distribution and by absorption in the soil.

Fig. 11. Construction of an energy HV distribution of 22 kV with electrically shielded conductors.

preceding measurements, the magnetic flux densities are again one order less than those for lines with classical bare limits and half an order less than magnetic flux densities due to power distribution using conductors with basic insulation. Decreasing distances from overhead shielded lines will slightly increase magnetic flux density without ever exceeding the reference value for current population under the Czech law 480/2000 Sb. or the maximum admissible value under the Slovak law 271/2004 Z.z.

Detection of the magnetic flux density due to underground shielded lines of 22 kV (see Fig. 10) gave the following results. The magnetic flux density emitted by underground lines for the heights measured is of the same order as that with classical overhead and insulated lines with the logical difference that an increasing height above the ground (*ie* decreasing height in the direction of bare lines) increases the emission of the magnetic components, and the emission of magnetic component due to underground shielded lines increases in the direction of the ground level, *ie* in the direction of installation of shielded underground cables. The soil carrying shielded lines, it is true, prevents, as a result of reflections, any leakage of the electrical ELF EMF component, but it is no absorbing medium for magnetic components. Within the interval $(2 \times 10^{-8}–1.5 \times 10^{-7})$ T magnetic flux density achieves values that are lower by 3.5 orders than the references values according to the Czech law 480/2000 Sb. and the Slovak law 271/2004 Z.z.

5 CONCLUSION

The preceding text brings results of detecting the electric and magnetic components of ELF EMF with a frequency of 50 Hz emitted by energy HV distribution of 22 kV. The measurements involved various types of HV lines, namely distribution with classical bare lines, distribution using conductors with basic insulation, shielded overhead lines and shielded underground lines.

The relatively high emissions of electric components of low-frequency ELM fields for classical lines of 22 kV with bare and insulated conductors are reduced by appropriate electrical parameters of underground and overhead shielded HV distribution. For bare and insulated conductors the measurements at certain heights will give values higher than 5 kV/m. (This is a reference value in the laws relating to protection of health against non-ionizing radiation, see 480/2000 Sb. in Czechia, and the maximum admissible values by the271/2004 Z.z. in Slovakia.)

The magnetic component of low-frequency EM fields (which, according to [9], is a dominant factor acting on electrically conducive human organisms) for bare lines, insulated lines as well as shielded underground and overhead energy distribution on the boundary of protection zones does not amount to the reference values 0.1 mT for current population by the Czech law 480/2000 Sb. nor the maximum admissible values by the Slovak law 271/2004 Z.z. With diminishing distances from bare conductors of the HV distribution under our measurement the emitted magnetic component will grow, but without reaching the value 0.1 mT (50 Hz) on the boundary of protection zone.

This value is a reference value for current population in the Czech law 480/2000 Sb. and the maximum admissible value for current population in the Slovak law 271/2004 Z.z. For magnetic components the protection zone for energy distribution of 22 kV (boundary position) fulfilled the legislative of the both nations.

Some medical studies [9] indicate a certain possibility (very low probability) of infantile population falling ill of leukaemia when exposed to ELF EM fields of frequency 50 Hz (under HV lines) with emissions of magnetic components amounting to 10^{-6} T. In cases with this level, it would be suitable to use, over the inhabited space and instead of bare HV lines, shielded overhead or underground lines of 22 kV with small emission of electric and magnetic ELF EMF components. Attention should be drawn also to the increased emission of magnetic components with underground shielded lines, close on the surface of the ground to be measured because a layer of soil of 1 m thickness do not absorb the magnetic component. Yet its value quickly goes down with growing heights above ground.

With electric ELF EMF components emitted by bare and insulated conductors, as demonstrated by the preceding text, the reference value for current population according to the Czech law 480/2000 Sb. and the maximum admissible value for population according to the Slovak law 271/2004 Z.z. will be reached and exceeded. It would be therefore advisable to consider an enlargement of protection zones, especially in the Slovak legislation, and authorize constructions on the boundary of protection zones only to a certain height, or in cases of constructions to be authorized on the boundary of protection zones, to support the building petition with results obtained in measuring (calculating) the components E (and also B) from HV lines of the same type.

The presented values are comparable with values given for energy distribution constituted by bare classic distributions in [13, 14]. As the legislation and related problems are very young the stated results for shielded and insulated conductors are original.

The Slovak law 271/2004 calls the values 5 kV/m and 0.1 mT of frequency 50 Hz, applicable to current population, the maximum admissible values, when as the Czech and EU legislations call them reference values. It would therefore be recommendable to extend the text, if the law should be amended, by maximum admissible values derived from the maximum admissible density of current, as carried out in the EU legislations. [7, 8].

Acknowledgement

This study was effected under financial support of JME Brno (South Moravian Energetics, Czech Republic) [12]. The measurements of B and E under the HV lines 22 kV took place with participation of students of doctor's studies who will use the experimental results to compare modelled values in the programme ANSYS (Ing. J. Mička).

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Received 12 August 2005

Eleonora Čermáková (RNDr, CSc) born in 1941 is with Department of Physics, Faculty of Civil Engineering, Brno University of Technology, Czech Republic. She is working as lecturer and is interested in ELF EMF including of non-ionizing radiation protection legislative.