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Fluctuations of electromagnetic field components under high voltage lines

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Abstract

High voltage (HV) Lines are part of the national electricity system. They are used for electrical power distribution between the power plant and the recipient. In addition to fulfilling this function, they generate unintentional electromagnetic field (EMF). In order to reduce the field impact on animate and inanimate objects it used to be determined under HV lines protection zones and technological. During electricity transmission occur PEM interferers, which process is dependent on changes e.g., voltage dips, short interruptions or in system. Voltage and current in changes the line superimpose on the alternating electromagnetic field produced by the HV lines and form a modulated waveform signals of different frequencies (50 Hz fundamental frequency, interharmonics and harmonics systems).

Keywords: High voltage (HV) Lines, electromagnetic field (EMF), modulated waveform signals

1 Admission

High voltage (HV) is an integral part of the national power system. They are used for transmission, distribution (distribution) of electricity between the power plant and the consumer. In addition to performing this useful function, they unintentionally generate electromagnetic fields (EMFs), which in the vicinity of the HV line reaches very high values - proportional to voltage (electrical component of the field) and current (magnetic component of the field) [1,2]. In order to limit the impact of the above-mentioned field components on animate and inanimate objects, protection and technological zones are designated under HV lines. A protection zone is an area located in the immediate vicinity of a power line. Its surface area is usually much larger than the area of the energy belt lying directly below the HV line. The zone is a lane connected from any use - prohibition of construction and performing any work (purpose: the need to protect people against PEM, the effects of HV line failure - e.g. breaking, short circuit or the occurrence of effects related to the interference of electronic devices - compatibility electromagnetic). The technological belt is identified with the zone that is used to service HV lines and devices used for transmission and distribution of energy. Designated refs under HV lines allow free access to power services to perform operational works, and also limit the impact of the electromagnetic field on man (the value of individual electromagnetic field compositions is approximately proportional to the distance from the HV wire) [1,6,11,12]. The operating current, which is distributed to consumers in high voltage (HV) lines, depends on the load and voltage of the HV network. For HV lines with a rated voltage of 220 kV, the value of the load current (working) is respectively:

- for ambient temperature $T = 0^0$ C, the operating current can vary from 830 A - to 1170 A;
- for ambient temperature $T = 25^0$ C, the operating current can vary from 518 - to 895 A [2,4,5,6].

HV lines use various systems to monitor the status of operating currents. For example, in the 110 kV line, a dynamic current carrying capacity (DOL) monitoring system [5,6] was used. This system uses the measurement of the cable temperature and weather conditions at the place of installation on the HV line. The determination of these two

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parameters allows to determine the dynamic load capacity of the line. Overhead lines are part of the power system for which no power or rated current is specified, only the rated voltage is plotted. The permissible value of current in the HV line results from the need to meet two conditions:

- maintaining the permissible overhang of the cable, i.e. maintaining a minimum distance from the ground so that safety requirements are met;
- preventing the maximum temperature for a given type of cable from being exceeded, e.g. 80°C for aluminium cables [1,2].

2 Fluctuations of EMF components under the HV line

In HV lines there is a dynamic change in time of load currents and rated voltages caused by various dependent or independent phenomena (atmospheric conditions) for reception. In HV lines there are various types of disturbances related to the transmission of electricity, e.g. voltage changes and fluctuations, dips, short bursts or overvoltages - Figure 1.

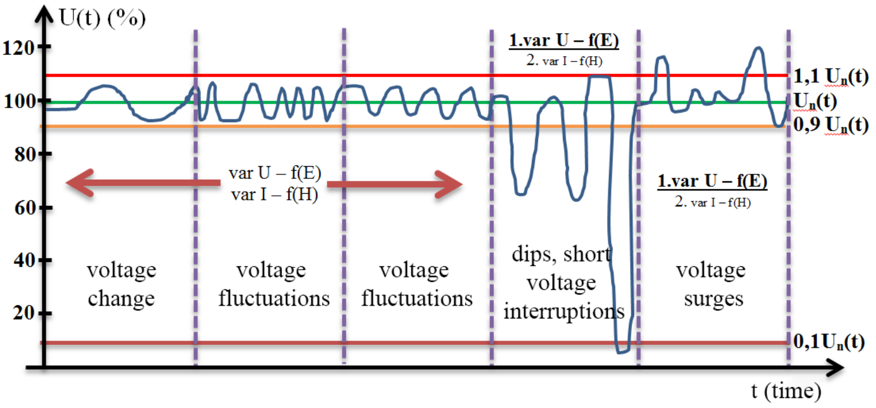


Figure 1. Supply voltage disturbances occurring in an industrial network Elektroenergetic

Voltage dips in the power supply network are called a sudden decrease in the effective voltage value, after which the voltage returns to the initial value after a few periods to many seconds - Fig. 2 [1,4,6,11]. The causes of voltage dips are disturbances in the network caused by, for example, shorting the line wires, switching on the high-power receiver(s). During the test of resistance of electrical and electronic devices against the risk caused by the collapse is characterized by two parameters:

- **dip level** expressed as a percentage;
- **duration** expressed, for example, by the number of periods of mains voltage - Figure 2.

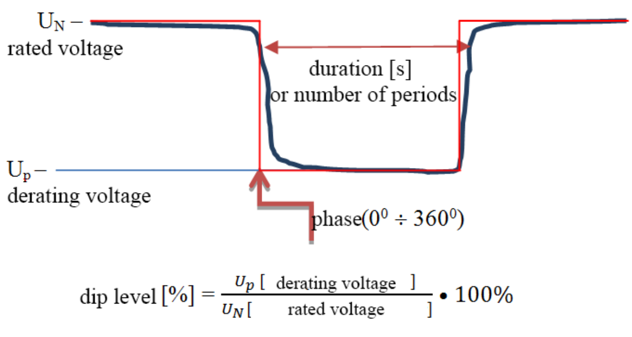
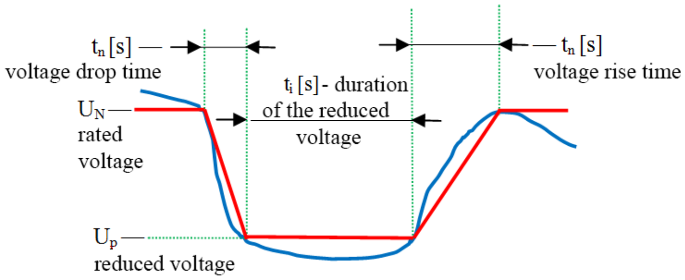


Figure 2. Determination of the duration and level of voltage surge in the industrial network

Short power interruptions occur when the effective voltage value is less than 10% of the rated voltage U_N - Figure 1. Additional parameter which characterizes the occurrence of short breaks is their duration - Figure 3. Short power outages are caused by various phenomena, such as, for example: HV switches/stops, short circuits, lightning, etc. [1].



$$\text{reduced voltage level [\%]} = \frac{U_p}{U_N} \cdot 100\ \%$$

Figure 3. Determination of the duration and level of voltage change in the industrial network

A change in voltage in a power line is called a gradual change in the supply voltage to a lower or higher value than the rated voltage U_N - Figure 1. The value of the supply voltage at different points in the distribution network is changed over time. The magnitude of these changes and their nature depend on various factors, e.g. changes in the load on the power grid, the dynamic nature of the operation of electricity consumers - thyristor devices, voltage rectifiers, motor speed controllers, etc. (these are devices converting electricity with nonlinear characteristics), power automation activities, interruptions which are caused by the occurrence of failures and in the network [1,4,6]. The parameters characterizing voltage changes are the level of voltage reduction from the rated value U_N and the duration of the voltage change - Figure 3. Due to the operation of electronic devices, an important parameter is also the rate of change of supply voltage (the rate of voltage changes dU/dt determines the frequency range of EMF interference produced by the HV line). The "normal" operation of some electronic devices is disturbed when the voltage change does not take place in a very short time of a few to several seconds μ (e.g. electric motors), but occurs in milliseconds or seconds - Figure 4. Devices susceptible to very short voltage changes of the order s μare, for example, sets of computers, laptops, controllers using embedded memory, microprocessors, detectors of fire alarm systems that have their own electrical signal treatment system, etc.

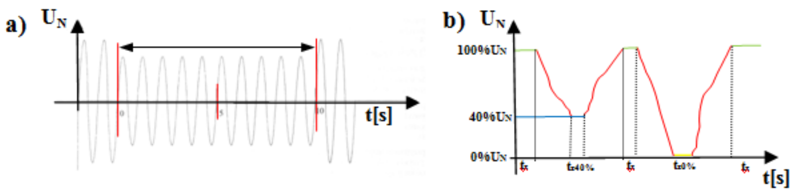


Figure 4. Voltage sag a) 70% surge level, voltage sag duration T = 10 waveform periods,
b) change of supply voltage

The result of the action of EMF produced by HV lines on devices (systems) is a change in, for example, resistance. The immunity of an electronic device or system to the presence of an electromagnetic disturbance produced by the HV line can be defined as the ability to operate this device without unduly degrading the quality of its functioning. The results of immunity tests should be classified in terms of, for example, loss of function or degradation of the quality of operation of the device (system) in relation to the level of performance quality set by e.g. the manufacturer or constructor [7,8,9]. The following assessment criteria shall be used to determine the resistance of devices (systems) to the effects of EMF produced by HV lines:

- normal operation within the limits specified by the manufacturer of the device;

- temporary loss of function or degradation of performance that resolves after the occurrence of EMF disturbances produced by the HV line (the device returns to normal operation without operator intervention) [7];
- loss of function or degradation of the quality of operation, proper operation of the device requires operator intervention (e.g. system reset/reset);
- loss of function or a decrease in the quality of operation, which can not be removed due to damage to the device (system), program or e.g. loss of damage.

Earlier by plotting permissible changes in EMF components, which are unintentionally generated by HV lines, may cause, for example, changes in the design of an electronic device - e.g. arrangement of semiconductor elements insensitive to EMF (printed circuit board), the use of screens or for the use of elements (subassemblies) electronic with an increased level of immunity to electromagnetic interference [8,10].

3 Results of measurements of changes in electric field strength E and magnetic field induction B under HV lines

In order to determine the above-mentioned EMF components, the distorted electromagnetic environment around the HV line should be periodically diagnosed (i.e. measured in accordance with the standards). Fig. 5 shows a measuring station for testing unintentional electromagnetic radiation, which is produced unintentionally (side effect of electricity distribution) by HV line. The measuring point under the HV line was located in the place where the individual components of the electromagnetic field (E, B) reached their maximum value. According to Polish standards, EMF measurements were made at a height of 1.2 m above the earth's surface. The tests were carried out at a positive external temperature, which varied within the range from +12 to + 18 ^{0}C. Fig. 5 and 6 show the time fluctuations of changes in magnetic field induction B and electric field strength E for two HV lines with different rated voltage:

- line no. 1 - rated voltage of the line 220 kV;
- line no. 4 - rated voltage of the 110 kV line.

The procedure for measuring the individual components of the EMF (E, B) under the HV lines was as follows:

- the reading of individual electromagnetic field components (E, B) was carried out every 2 within 60 s;
- the maximum values of individual components of the electromagnetic field for a given moment of measurement were assumed, for three series of measurements of individual components of the field E, B, the average value was calculated, which is presented in diagrams 6, 7;
- measurement of individual components (B, E) OF EMF was carried out for two frequency bands:
    - ELF - frequency range up to 5 to 2,000 Hz;
    - VLF - frequency range up to 2 to 100 kHz.

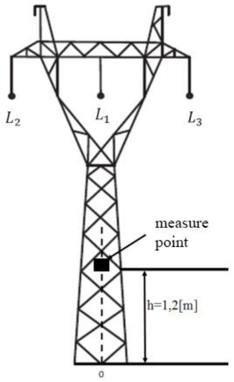


Figure 5. Diagram of the measuring station for determining the fluctuations of the components of the electromagnetic field B, E as a function of time

Figures 6, 7 present the results of measurements of individual components of the electromagnetic field E, B for two HV lines - line no. 1 (220 kV) and line no. 4 (110 kV). Diagrams 6, 7 show the maximum values of this field, which were obtained as a result of a series of measurements. As a result of a series of measurements for magnetic field induction B for the ELF frequency range over a time of 60 s for lines 1 (220kV) and 4 (110kV), the following regularities can be observed:

- the magnetic field induction B fluctuates around a mean value of 0,65 μT for HV line No 1 and 1,40 μT for HV line No 4;
- the trend line of changes in the induction B of the magnetic field during measurements is shown in Figure 6;
- for HV line no. 4 (110 kV) the fluctuation (trend line of change) in the flux B of the magnetic field at the time of measurement was much greater than for line 1 (period of change of value approximately equal to about 30 s);
- for HV line No. 1, during the measurements, a slow increase in the induction B of the magnetic field in time to 50 s could be observed, and then a slow decrease to the initial value of B = 0.52 μT;
- the rate of fluctuation of the induction B of the magnetic field at the time of the measurement was much higher for HV line 4 than for line 1, which may lead to the conclusion that there are larger changes in load current in this line.

The maximum changes in induction ΔB of the magnetic field during measurements are illustrated in Figure 6 and are respectively:

- line no. 1 - maximum change of value $\Delta B = 0{,}3$ [μT];
- line no. 4 - maximum change of value $\Delta B = 0{,}5$ [μT].

In Figures 6, 7, the t-line of changes in the measured induction values B of the magnetic field is marked in black.

When measuring the induction B of the magnetic field, the following trends in values can be observed:

- the induction B of the magnetic field changes its value (oscillates) around the average value - B = 1.4 T for line 4 and B = 0.62 μ T for line 1μ;
- the average value of the induction B of the magnetic field depends on the value of the load current that occurs in the power line;
- changes in the ΔB induction of the magnetic field depend on the current and rated voltage of the power line.

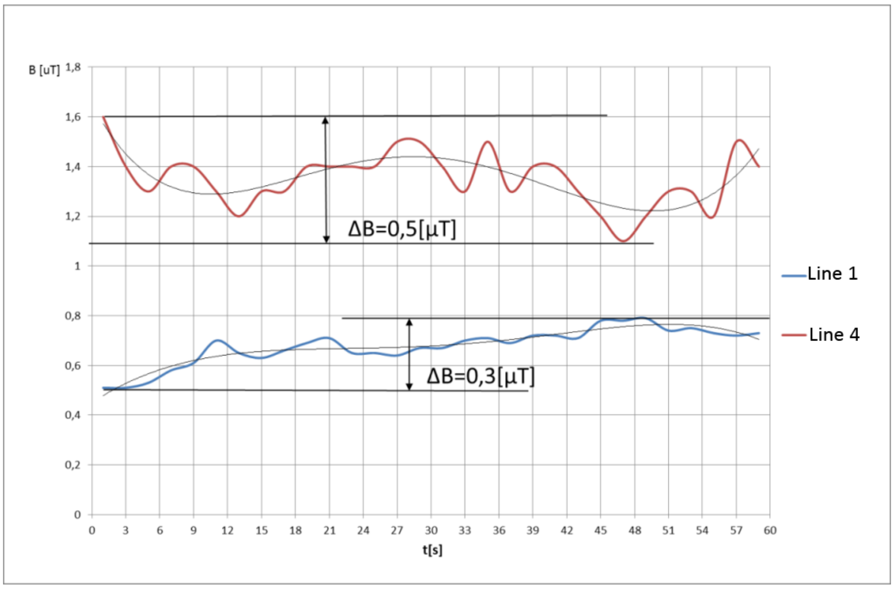


Figure 6. Induction B of the magnetic field under HV lines no. 1 (220kV) and No. 4 (110kV) for the ELF frequency band

The induction B value of the magnetic field for the VLF frequency range varied from 0.2 to 0.4 nT during the measurement. The field values obtained as a result of measurements and their changes may indicate that the HV lines are not a generator of disturbances in this frequency range, i.e. in more than 2 kHz. During the "normal" operation of the line, i.e. no short circuits, switches, surge currents from lightning, etc. Excessive values of the B magnetic field induction are not to be expected.

Figure 7 shows the changes in electric field strength E obtained during measurements over 60 s. The measurement procedure used when measuring this component of EMF was similar to the measurement of the B induction of the magnetic field. The maximum value of the electric field intensity E under line no. 1 - 220 kV is 2.0 kV/m, while for line no. 4 - 3.25 kV/m. During the measurements, it can be seen that the value of the intensity E of the electric field increases with subsequent measurements for line 4 and stabilizes at a constant level of 3.25 kV/m. Fluctuations during measurements of the intensity E of the electric field were within the limits ± 80 V/m after the value of this field has stabilized, i.e. after 30 s from the start of the series of measurements. For HV line No. 1, the value of the electric field strength E fluctuates around the average value of 1.65 kV/m. In the initial time of performing a series of measurements, i.e. from 0 to 15 s for two HV lines – 1, 4, an increase in the E intensity of the electric field can be observed for individual lines:

- line no. 1 - fluctuations in electric field strength kV/m $\Delta E = 0{,}50$, change of value from a minimum of 1.5 kV/m to a maximum value of 2.0 kV/m;
- line no. 4 - fluctuations in electric field strength$\Delta E = 0{,}75$ kV/m, change of value from minimum 2.5 kV/m to maximum value 3.25 kV/m.

The increase in the E value of the electric field in the initial measurement range did not result from the operation of the measuring instrument, i.e. the error that is brought after switching on the meter and stabilizing its indications. All omissions were performed after 60 - 90 s after switching on the meter and maintaining the appropriate distance sensor - person performing the measurements. This is the time that is necessary for the meter readings to stabilize - i.e. to obtain appropriate technical parameters of the instrument, e.g. sensitivity. Before and after switching on the meter was within the range of force lines of the electric field produced by the HV lines.

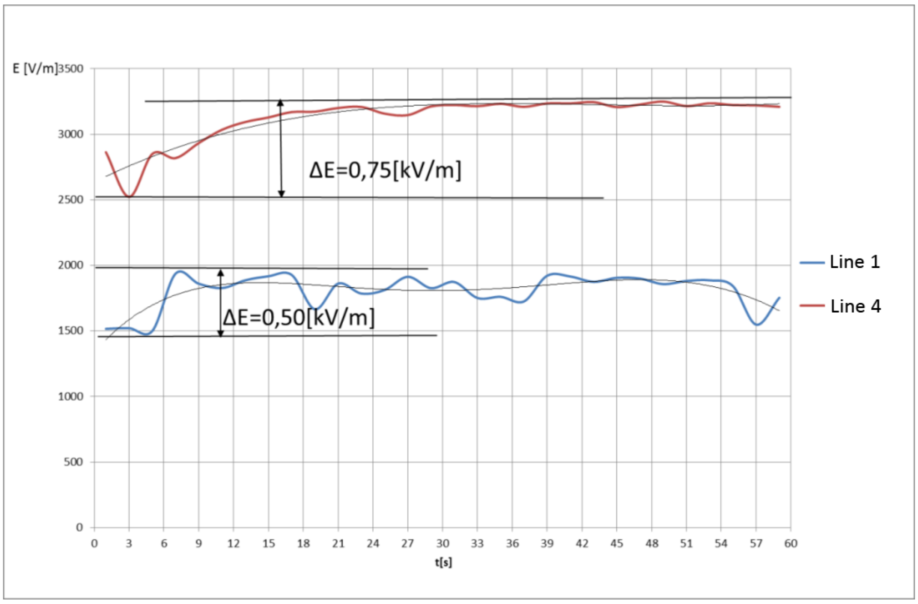


Figure 7. Electric field strength E under HV lines No. 4 220kV and No. 1 110kV for the ELF frequency range

4 Conclusions

HV overhead power lines with a rated voltage of 110kV or higher in accordance with the standards and principles of line design should be designed so that vertical and horizontal distances from building elements indicated in Table 1 are maintained. The standards and regulations specify areas of the first stage where the electric field strength exceeds the value of 10kV/m, and areas II where the electric field strength is within the range from 1kV/m to 10kV/m at the highest operating voltage of the device [4,5,6,7,11]. Changes in voltage and operating current in HV lines are the cause of fluctuations in alternating electromagnetic fields generated unintentionally by HV lines – Figures 8, 9.

Table 1. Distance from HV line to the nearest part of the building(s) ensuring that the EMF value is not exceeded as a function of HV line voltage [3]

Line rated voltage kV	Distances from the line to the nearest parts of the building(s) ensuring that the EMF size is not exceeded	
	10 kV/m	1 kV/m
110	4	14,5
220	5,5	26
400	8,5	33
750	15	65

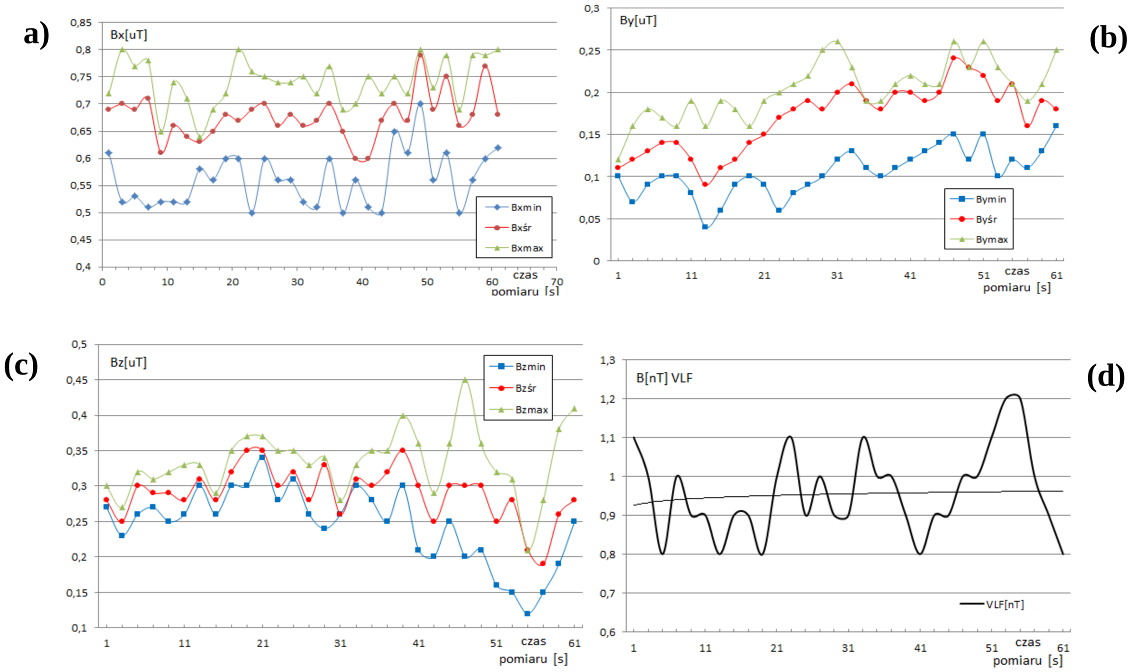


Figure 8. Fluctuation magnetic field induction B under HV line 110 kV double-track [(a) component B_x; b) component B_y; c) component B_z] – ELF frequency range, d) B[nT] - Frequency range VLF

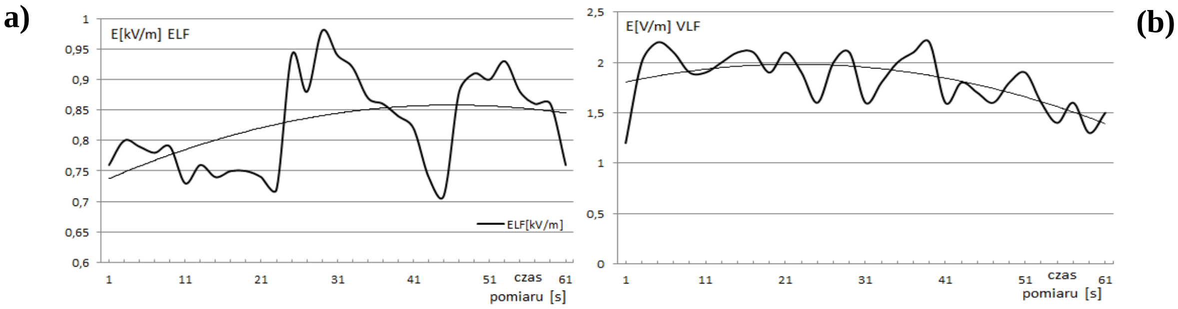


Figure 9. Fluctuation of electric field strength E under the HV line 110 kV dual-path a) electric field E strength ELF; b) electric field E strength VLF

Figures 8, 9 show the occurring fluctuations of electromagnetic field components for two frequency sub-ranges. Individual components of the induction B magnetic field B_x; B_y; B_z – Figures 8 a-c changed during the measurements, but the dominant component is the component of the field B_x. The range of changes of this component is: max 0.8 T and min 0.5 T. Changes in voltage and current (increase, decay, collapse, etc.) overlap with the alternating electromagnetic field produced by HV lines creating a modulated course of signals of different frequencies (basic frequency 50 Hz, and even or odd interharmonic and harmonics). The occurrence of electromagnetic interference around the HV line may cause, for example, eddy currents in an underground metal installation that is located near the HV installation, interference with the operation of electronic devices – radio and television receivers.

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