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ELECTOMAGNETIC FIELD IN HUMAN ENVIRONMENT AND METHOD OF ITS DETERMINATION

Показано приклади джерел електромагнітних полів включно з їхньою можливою небезпекою. В останньому розділі статті наведено методи графічної інтерпретації полів навколо високовольтних ліній. Природна напруженість електричного поля навколо Землі оцінюється величиною 100–150 В/м , проте під час грози вона сягає 20 кВ/м. Магнітне поле Землі є оптимальним для існування життя і його розвитку. Магнетизм землі сягає 47 µТ. Живі організми створюють незначне магнітне поле, що є протилежним до магнітного поля землі. Існує багато джерел електромагнітних полів: електричні установки в будинках, промисловості, транспорті, а також широке коло домашніх електричних пристроїв.

Paper presents examples of sources of electromagnetic fields and possible dangers involved. Last chapters of paper presents methods leading to graphical interpretation of fields around high-voltage lines. Natural intension of electric field over Earth assumes value of 100-150 [V/m] but by thunderstorm reaches 20 [kV/m]. Earth's magnetic field is optimal for existence of life and its growth. The magnetism of earth reaches 47 [µT]. Live organisms induces a slight magnetic field, that is contrary the magnetic field of the earth. There are many sources of electromagnetic fields, electric installations used in buildings, industry, transport, and wide range of house devices.

Introduction. At present, it is very difficult to do without electrical energy. Its use involves induction of electromagnetic field. Natural and induced electromagnetic fields therefore, accompany people everywhere (place of residence, at work), and development of many branches of technique is responsible for electromagnetic field's occurrence.

Electromagnetic field becomes the subject of consideration in context of its negative influence of environment and human health. Both electric and magnetic field are frequently discuss separately.

Recently, problems of conservation of environment and human health protection gain greater importance. On the basis of investigations run by international organizations, new regulations are set to keep people out of harmful influence of electromagnetic field.

This paper presents main sources of electromagnetic field and scale of danger and protection from these fields. Second part of paper presents method of determination of field in surrounding of electric lines.

Sources of electromagnetic fields. During discussion on subjects of phenomenon and electromagnetic effects, magnetic and electric fields are discerned and talked over separately. Electric field is induced by difference of potentials (voltage) between two points in the space, and kV/m is unit of its intensity. Natural intensity of electric field near to Earth's surface and in condition of good weather is of 100-150 V/m. During storm weather may reach about 20 kV/m. Electric fields are essentially screened by outer layers of conducting matter of living organisms, and hence these fields practically don't pervade inside these organisms.

Magnetic field however, is induced by a flowing current. In this case, two characteristic values may be pointed. One of them, intensity of magnetic field, of unit expressed in A/m, and magnetic induction in T unit. Magnetic field depends on latitude and may reach values between 20 and 60 A/m. Magnetic fields are slight screened by conducting materials, pervade living organisms and hence may heat their bodies.

Making consideration of this field, surface power density is estimated and measured in W/m^2, referred to surface of body or in W/kg, referred to a mass of human being. Values of electromagnetic field as well as frequency of its radiation, decide of level of harmfulness of these field on environment. Table 1 presents acceptable levels of electromagnetic radiation.

There are many sources of electromagnetic fields: all devices and electric installations, run in power industry, industry, buildings and transport. Sources of electromagnetic fields are divided into few groups. First group is made up of stations and power lines. Next group, relay stations used by radio, television and mobile telephony, sender-receiver stations ensuring communications and detecting of objects. Separate group are industrial devices and devices and installations of low voltage. Last group, devices run in household, public objects, trade centers, offices and private and public transport. Also mobiles and CB-radios may be placed in this group.

Table 1

Acceptable levels of electromagnetic radiation

Radiation	work environment (8h)	Living area (24h)
Electric field	10 kV/m	1 kV/m
Magnetic field	66,7 A/m	60 A/m
Magnetic induction	83,7 μT	75,36 μT
Energy density	2 W/m^2	2 W/m^2
SAR*	10 W/kg (pracownicy)	2 W/kg (ogół ludności)
*SAR (specific absorption rate) – speed of absorption. Specifies termal danger, induced by microwave radiation.		

Frequency of electromagnetic fields is their very important parameter. Electromagnetic radiation includes very wide spectrum of frequency (it is presented on fig.1). There is conclusion, that electromagnetic field is induced by power lines as well as field of mobile systems, visible radiation, X-radiation, radioactive element radiation.

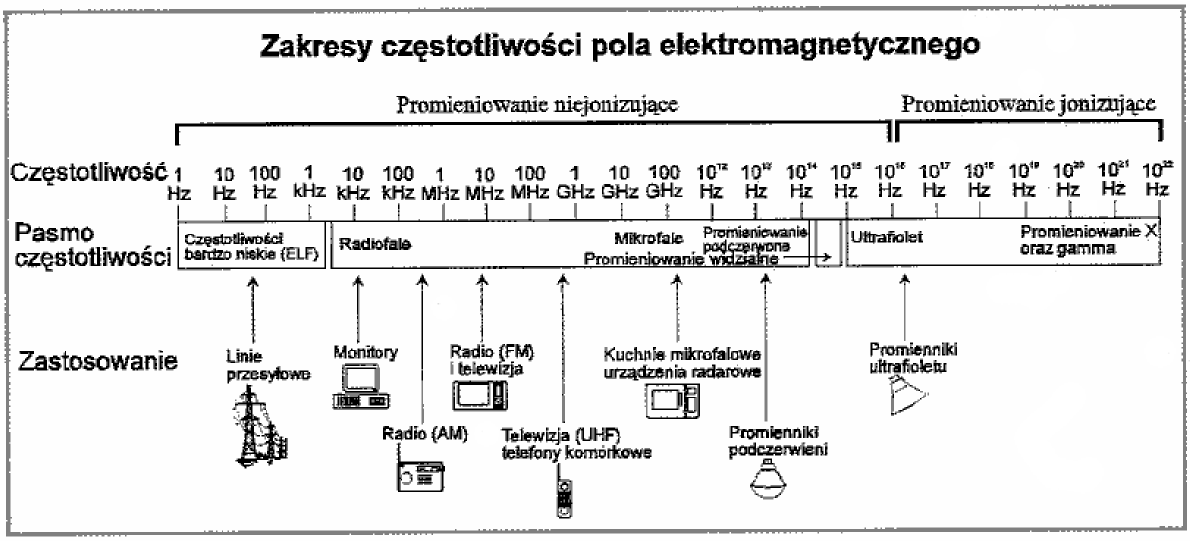

Fig. 1. Spectrum of electromagnetic radiation [9]

Length of wave decreases and energy of wave increases with frequency of radiation. With wave length, two concepts are involved: near and far field. Near field is analyzed if observer is in distance from source of radiation, that length is shorter than wavelength divided by 2π. If distance is longer than wavelength divided by 2π, field is defined as far field. Near field has advantage, that render possible separate analyze of both its component: electric and magnetic. In case of far field, it's impossible.

For various frequencies, electromagnetic field has other properties and this occasion involves other divisions into ranges of similar parameters. As an example, ionizing and non-ionizing radiation can serve. This case, border of radiation oscillates on level of 10^{16} Hz.

Significant band, worth to indicate, are fields of extremely low frequency (ELF), that reach up to 300 Hz. This band includes technical frequency (50/60 Hz), that is characteristic of electrical power engineering's infrastructure. Its special properties are consequence of its commonly usefulness and as a fact, that this field is relatively new, artificial, invented by people, and still poorly investigated.

Problem of exposition in electromagnetic field and its harmfulness is very important however. Environmental exposure is of great importance, and means that people without any restrictions and time limitations may be exposed to a field. Electrical installations and electrical devices of common use belong to mentioned category. Exemplary values and effects of sources are set and presented in table 2.

Table 2

Levels of electric and magnetic field of 50 Hz frequency, that occur in environment

Overhead lines	Electric field intensity [kV/m]	Magnetic field intensity [A/m]
Under highest-voltage lines (220–400 kV)	1 – 10	0,8 – 40
In the distance of 150 m from 400 kV-line	below 0,5	below 4
Under high-voltage lines (110 kV)	0,5 – 0,4	below 16
Under medium-voltage lines (6–30 kV)	below 0,3	0,8 – 16
Out of high-voltage substation	0,1 – 0,3	below 0,2

Since electromagnetic waves and their existence were experimentally confirmed, analyzed, and subsequently put into practice, natural Earth's environment is successively enriched with sources of radiation. In case of high-frequency fields (above 100 kHz), few sources of generation should be enumerated. Especially there are radio communication systems, devices operating in industry, science and medicine as well. This fields involves phenomenon called thermal effect and lies in absorption of electromagnetic field by matter (e.g. human body), and may triggers of local or global increasing of temperature. This phenomenon is of negative character, although is used in intended way.

Radiation emitted by mobile telephony is worth of mention too, because is ubiquitous for some time now. Mobiles, sending and receiving devices of not large power, radiated by antenna (2W), use digital systems of data traffic, in band included between 900 MHz and 1800 MHz. Establishing a call, telephone reaches maximal power and decrease it after obtaining a connection, all along is situated very close to head. In head, all electromagnetic energy is concentrated and reaches significant values. One suggestion is therefore, to keep telephone at a distance, especially from head, during process of connection, when device is searching for a connection with a base station. Second method is, to limit the time of exposition nearby sources of field (to shorten time of phone call, using a cell hold nearby a head).

Actual restrictions, standards and recommendations linking to a protection against effects of electromagnetic fields. In Poland, juridical requirements are established for many years, regulate policy of protection of environment and human health from effects of electromagnetic fields. These regulations concern such a sources, whose territorial range is significant. Due to law, overhead lines of highest nominal voltage and substations are treat as harmful objects.

Juridical regulations on discussed subject distinguish two environments: work environment and accessible environment. Work environment is defined as an area (stretch), that is available for manufacturing only, and in most cases available for workers, those are open to high values of field and simultaneously short-term exposition. In turn, accessible environment, due to juridical regulations, is an area, on that people (including pregnant women and children, etc.) may stay non-restrictive, and are open to lesser values of effecting field, but time of exposition may be longer.

Basic juridical act, regulating issues connected with interactions of electromagnetic field, is Disposition of Minister of Environment, published on the 30th of October 2003, upon the case of acceptable levels of electromagnetic fields and methods of controlling if these levels are obeyed. In case of projecting and constructing of power lines in Poland, Polish Norm (PN-E-05100-1. Overhead power lines. Projecting and constructing. Alternate current lines without wire coats [12]) was valid. In august 2005, Polish Norm PN-EN 50341-1 was set, that differs from formerly valid. In new norm, the shortest acceptable distances between phase wires are specified. There are ambiguities between two foregoing documents, that put problems with interpretation.

From requirements of Polish Norm [12], few notations may be quoted. Electric field intensity, that is induced by overhead lines, should not exceed 1 kV/m at the height of 1,8 m above the ground level and at the same distance from buildings and other surfaces (hospitals, kindergartens, schools), within people spend more than 8 hours a day. Besides, electric field intensity should not exceed 10 kV/m at the height of 1,8 m above the ground level and other surfaces (roofs and terraces), where people spend not more than 8 hours a day. These requirements have influence on selection of the smallest acceptable vertical distance of overhead line's wires from surface of ground, by the greatest slack of wires.

In the line of environment protection, above-mentioned regulation specifies acceptable levels of electromagnetic fields in environment (different for: terrain destined to a build-up and area freely available to people), bands of frequencies of electromagnetic fields, for which physical parameters are specified, and those characterize interactions of electromagnetic field on environment. Regulation introduces methods of determination and keeping the abidance of permissible levels of electromagnetic fields.

Border limits of intensity of electric and magnetic field component (50 Hz) differs in other states. Valid norms in individual countries, are set on the basis of still updated views and new biomedical investigations as well. There are few organizations, that run such an investigations, therein World Health Organization (WHO*), International Radiation Protection Association* (IRPA/INIRC), International Council On Large Electric Systems (CIGRE), CENELEC etc. Lack of uniformly specified norms in UE's states, render harmonization of occupational and safety health' norms very difficult and regulations referring to environment protection. Thereupon, in 1995, project including the highest acceptable levels of fields was set and was established as not-valid recommendation.

Effect of electromagnetic fields on human environment and protection from EMF. Sudden development of contemporary technology, and hence increase of sources of EMF, caused, that problem of effect of these field on living organisms appeared, and possibility of pathological reactions of human organism occurred. Problem of interactions between electromagnetic instruments and people and environment, may be perceived to be far wider, taking into consideration a fact, that contemporary human being is broadly surrounded by electromagnetic fields, induced by variety of sources.

In environment, numerous electromagnetic sources occur, in wide band from few Hz to row of GHz.

Exposure from electromagnetic fields of 50 Hz, is considered as direct –effecting living organisms, and indirect –though effects accompanying phenomenon of partial discharge, such as acoustic noise and wireless transmission distortions.

For more than thirty years, in many famous scientific centers all over the world, investigations on influence of electromagnetic fields on healthy people and on environment are run. Problem of effects is analyzed in terms of technical, biomedical and social as well [11].

Despite of longstanding experimental and epidemiological trials, problem of relationship between magnetic field and morbidity on tumors stays still an open problem. Relationships between exposition to magnetic field and progress of tumor, that were established in numerous researches, are sufficient strong, that they shouldn't be disregarded and consider as accidental, and simultaneously so weak, that causal relationship should not be accepted.

Protection from unwelcome after-effects of exposition to electromagnetic fields is based in Poland from many years on initializing special, protection zones of electromagnetic fields and on evaluation of exposition of worker. Protection zones are defined in regulations applied to individual band of frequencies. First of them, is danger zone, within only workers equipped with protecting instruments them from harmful influence of field, may stay. In another zone, is emergency zone, within workers may stay in short time, less than 8 hours a day, and depending on value of intensity of electromagnetic field in point of work. Consecutive zone is indirect zone, within workers may spend not more than 12 hours a day. Last zone, so called safe zone, is area, that is placed beyond protection zones, within people may stay beyond limitations.

Similar principle, people may use with respect to electric devices, that are run in their houses, because intensity of electromagnetic field decreases with the square of distance.

Screening is one of the matter of protecting against EMF, that is used in work environment, and out of it as well. Realization of screening, that protects from electric fields is relatively easy and not very expensive. In case of protection from magnetic fields unfortunately, it's necessary to apply multilayer screens of special construction.

Owing to insufficient knowledge about ecological interactions of discussed fields, principle ALARA plays important role – As Low As Reasonably Achievable, that recommends minimization of endangers to a possibly low level with application reasonable technical means and capital expenditure.

Determination of electric and magnetic field intensity. The second part of paper focuses on numerical methods of determination of electric and magnetic field in surrounding of high-voltage lines. Respecting of frequency (50 Hz) used in electrical power engineering, both magnetic and electric field may be treat as static field and analyzed separately.

Intensity of electrical field is determined indirect. With nominal voltage of power line, distribution of electric field in analyzed area are determined, electric field intensity is calculated as gradient of potential.

Magnetic field (induction) in surrounding of power line may be calculated with Biot-Savarte Law [2]. This way is proper, if in surrounding of line, materials of ferromagnetic properties are not present (or of neglectful dimensions). It is necessary to stress, that instantaneous value of magnetic field depends on load of line, i.e. on current flowing in any moment. Maximal value of field in analyzed points, is calculated for maximal current of given line.

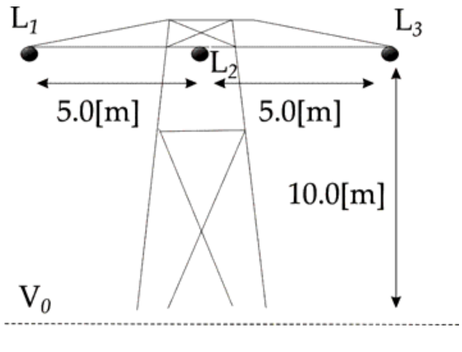

Fig. 2. Height and wires spacing

Finite difference method. Function of potential of electric field in area of power line is solution of Laplace's Equation. Receiving simplifications (neglecting of pylons, wires treated as infinitely long and straight), mostly, problem is considered as two dimensional. Precise computations of intensity of field in area of power lines are indispensable and present device to evaluation of relationship between height of pylons, distance of wires and whole geometry of line and intensity of field in surrounding of power line, and simultaneously to project power lines in such a way, to include the field in established criterion.

Potentials of wires ($L_1 : V_1 = V_n; \quad L_2 : V_2 = aV_n; \quad L_3 : V_3 = a^2 V_n$, where $a = e^{j2\pi/3}$) in view of ground poses boundary conditions, used in obtaining the solution. Obtaining of analytical solution of Laplace's Equation (for example with method of separation of variables) is very complicated, and in most cases impossible, numerical methods meet half way [4].

One of numerical methods, that may be used to this type of problems, is Finite Difference Method, consisted in approximations, that lead to replace partial differential equation with differential equation [6]. In FDM, analyzed area is split into even grid. For every element of grid (node), equation including values of adjoining nodes is derived. Certain, finite set of nodes have attributed constant values (real or complex), equivalents of potentials of ground or wires. According to a grade of complication of problem, there are few methods of solution of system of equations e.g. band and iterative method.

Advantage of FDM, is simple implementation, light to construct grid (mostly rectangular) and hence, simple formulas for grid with regular step, possible of building up the grid in subarea of special importance (e.g. surrounding of bundle wires).

Boundary conditions – image method. Boundary conditions are necessary to obtain, to render the Finite Difference Method useful. In case of problems of field in surrounding of high voltage power lines, there is lack of boundary conditions – open-problem [5]. Only potential of ground and consecutive wires or bundle of wires is given. To receive conditions on boundary of all area, within field is analyzed, Image Method was used. Leaving extents of analyzed problem, areas of given potential are replaced with electric charge. In symmetry to a ground plane (line in 2-D problems), opposite charges are placed and with their, directly intensity of electric field is determined in any point of area. Further, calculations with Image Method will serve to comparison and evaluation of efficiency of solution.

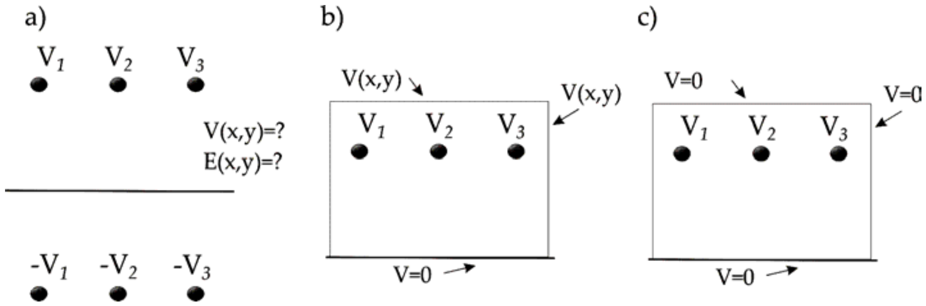

Fig. 3. Boundary conditions:
a – Image Method; b – Finite Differential Method with boundaries received with Image Method;
c – FDM with zero-boundary conditions

Fig. 4 presents potential of electric fields in area of three-wire line. Other graphs are of qualitative character – value of potential in given point is proportional to established nominal value of line voltage.

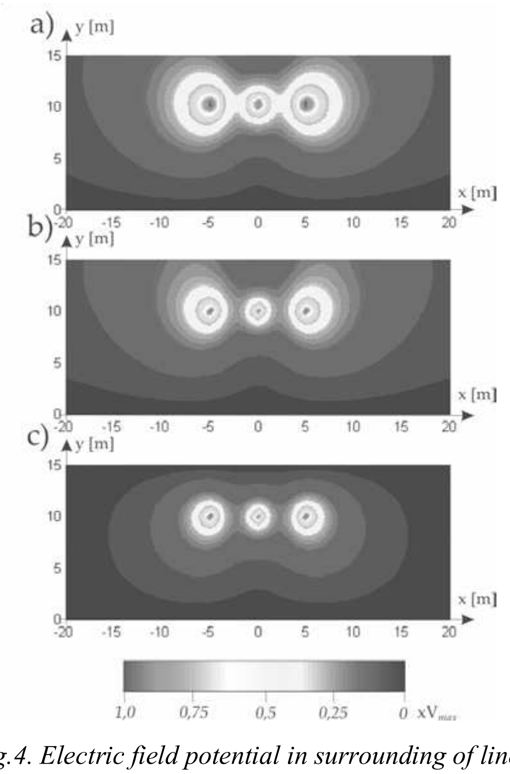

Fig.4. Electric field potential in surrounding of line:
a – Image Method; b – Finite Differential Method with boundary conditions received with Image Method; c – FDM with zero-boundary conditions

Fig. 5 is to compare exact results received with other methods and presents intensity of field at a height of 2 meters above the ground level, under the 110 kV-line. Analyzed area of height of 15 meters and width of 40 meters. Discretization step is equal 0,1 m.

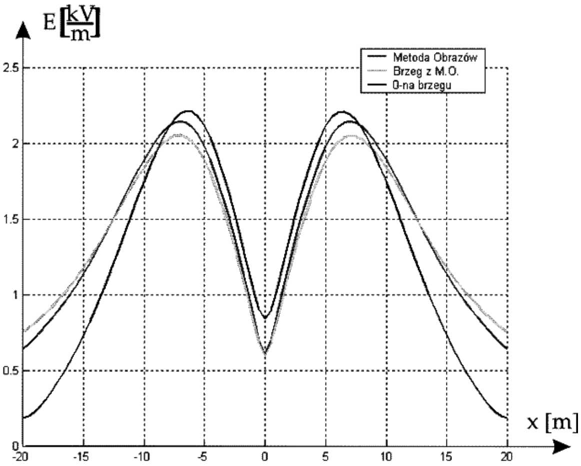

Fig. 5. Electric field intensity under 110-kV line at a height of 2 meters above the ground level, received with 3 methods

Conclusion. In the paper, actual state of knowledge on harmfulness of electromagnetic fields was discussed. World-wide organizations, that lead investigations, don't have confirmed arguments, that fields of frequencies of 50 Hz in surrounding of power objects, may trigger off rumor diseases among people. It is impossible to definitively affirm, that above-mentioned is true. It's recommended to reasonably limit and avoid such fields.

For many years, in Poland, juridical system regulates principles of protection of environment from harmful influence of electromagnetic fields. This paper includes actually valid recommendations, that concern value of components: electric and magnetic. In Poland, values amount to 1 kV/m for electric component and 60 A/m for magnetic component (for the general public). Polish standards are one of the most restrictive in the world.

Paper introduces main sources of electromagnetic fields and scale of dangers and protection from them. The second part of paper presents method of solution of field in surrounding of power lines and problems that may occur in connection with this problem. Presented method of calculation of intensity of field, may be used after some simplifications are assumed, have application because of its not large scale of complications, and may be useful to analyze of influence of height of spans on value of field under the power lines.

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МОДЕЛЮВАННЯ ЕНЕРГООЩАДНИХ РЕЖИМІВ РОБОТИ ЕНЕРГООБЛАДНАННЯ

Проаналізовано причини зростання втрат і, як наслідок, зменшення ефективності роботи енергообладнання через старіння і деградацію. Розглядається питання доцільності застосування методів нечіткої логіки для контролю і управління ефективністю експлуатації турбогенераторів.

The paper presents the reasons for increase of losses followed by the reduction of energy plants efficient operation because of its aging and degradation. The issue of reasonableness in applying the fuzzy logic methods is raised for the control over the efficient utilization of turbine generators.

Постановка проблеми. Останнім часом особливо актуальною є проблема зниження питомих витрат умовного палива на енергоблоках ТЕС. Це зумовлено як дефіцитом паливно-енергетичних ресурсів в Україні, так і моральним та фізичним зношенням енергообладнання.

Незважаючи на профілактичні ремонти, після закінчення встановленого (розрахункового) терміну експлуатації енергоблоків ТЕС істотно знижується їхня ефективність не тільки через зростання частоти і обсягів ремонтів, але і внаслідок зростання експлуатаційних втрат.

Аналіз останніх досягнень та публікацій. Зниження витрати електроенергії на власні потреби на усіх електростанціях України лише на 1 % збільшує корисний відпуск електроенергії на 1100 млн. кВт. год. на рік.

Враховуючи те, що заходи енергозбереження на електростанціях мають велику ефективність і окуповуються за дуже короткий термін, необхідно використовувати методологію системного підходу до комплексного вирішення проблеми керування енергозбереженням в енергосистемі. Спрощено весь технологічний цикл можна розділити на фази: видобуток енергоносіїв і їх