Part 5

DECREASE IN PHYSICAL FACTORS IMPACT FROM POWER OBJECTS ON ENVIRONMENT

5.1. Decrease in impact of electric and magnetic fields of the industrial frequency on the person

5.1.2. Mathematical assessment and phantom measurements of electric and magnetic fields effect factor on the person

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5.1.2.1. Electric and magnetic fields under ALs of SHV

Electric fields, induced by ALs of SHV and ultrahigh voltage (UHV), are comparatively easy to estimate when they are arranged over the smooth ground surface. Indeed, the ground surface is not even. This leads to divergence of calculations and measurements approximately by 5%.

Magnetic fields at a typical (not ferromagnetic) ground over which there are ALs of SHV and UHV, are not distorted; divergences of estimating and measuring results are insignificant and lay in the limits of inaccuracy of measuring devices.

For assessment of EF and MF levels, induced by ALs, there are different methods and programs of estimation; one of them is "EMF line" program.

To estimate the levels of the fields influence on the person, who is close to lines of high voltage, plots of EF and MF strength distribution E_{max} and H_{max} at a level of 0,5; 1,5 and 1,8 m above the ground in AL cross-section of 110—1150 kV, are being built up. As an example, in Figs 5.1 and 5.2 the resulting curves of EF strength distribution E_{max} and H_{max} are shown at a level of 1,8 m in AL cross-section of 500 kV, depending on the distance between the bottom phase wire and ground. Calculations are made for line voltage of 500 kV and phase current of 1050 A.

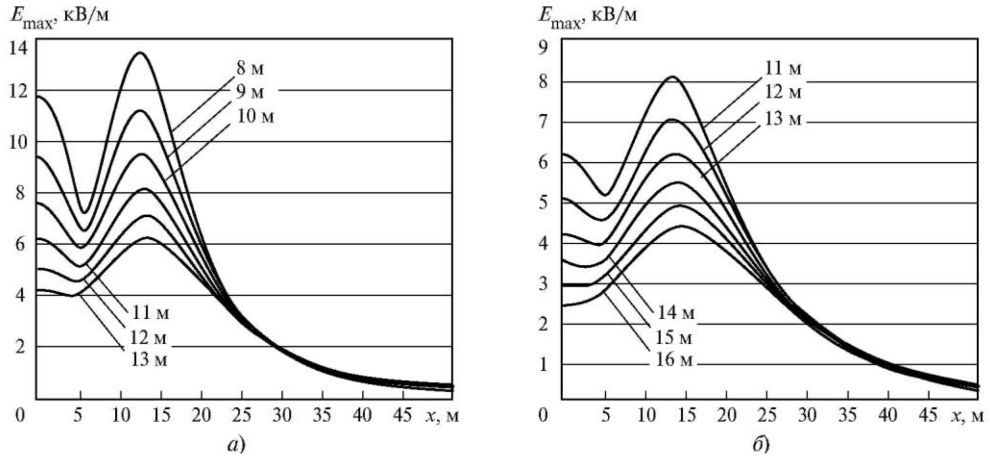

Fig 5.1. EF intensity distribution Emax in AL cross-section of 500 kV at a level of 1,8 m above the ground for parameters "bottom phase wire -ground" from 8 to 13 m (a) and from 11 to 16 m (b). м=m; кВ/м=kV/m

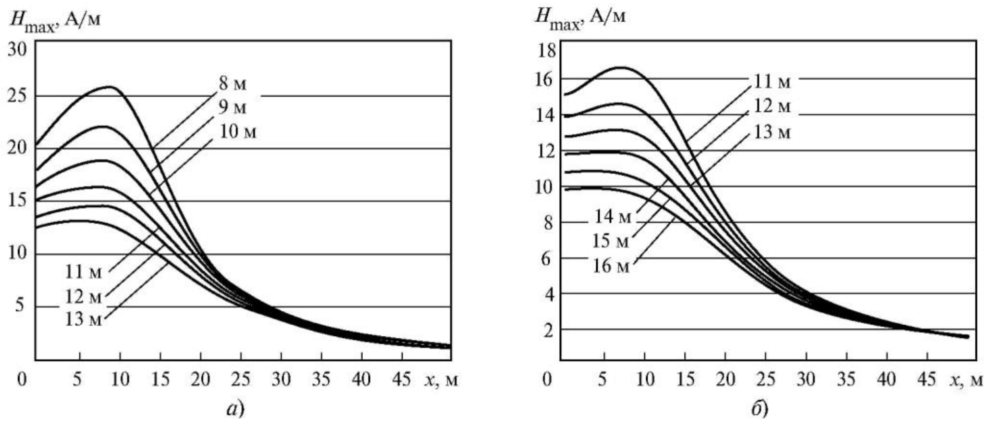

Fig 5.2. EF intensity distribution H_{max} in AL cross-section of 500 kV at a level of 1,8 m above the ground for parameters of "bottom phase wire-ground" from 8 to 13m (a) and from 11 to 16 m (b). м=m; А/м=A/m

These data allows the adequate assessment of the possible EF and MF levels both at the working places and also at the population residences, even at the stage of a project documentation development for APLs, and also its correction for exclusion of the mentioned above adverse effects on the person.

5.1.2.2. Step voltage under AL of SHV. Measurements of electric and magnetic field effect factors on the person

Routes of ALs of SHV and UHV cross the oil and gas pipelines, railroads and motorways, where breakthrough and spillage of oil products can occur. In Fig. 5.3 as example for ALs of 750 kV of a traditional implementation with parameters of 12 m, surfacing of φ_d module and a phase angle ψ_d of the potential on the oil saturated ground with relational dielectric permeability $\varepsilon = 3$ and conductivity $\gamma = 3 \cdot 10^{-9}$ 1/(Om•m) is shown. Under the middle phase a value of potential makes a zero. The line passes over the oil saturated ground.

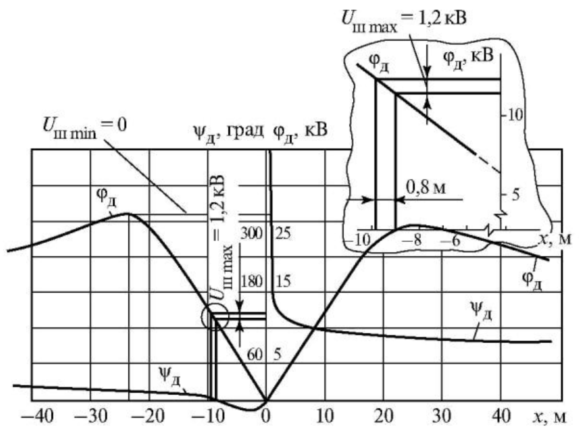

Fig. 5.3. Surfacing the potential at the oil saturated ground and estimation of the step voltage. φд, кВ=φ_d, kV; ψд, град=ψ_d, deg.

5.1.2.3. Magnetic fields in a zone of works under voltage at ALs of SHV

During performance of works under voltage (PWUV). line personnel is in the intensive MF that is not screened by the defender.

To estimate MF intensity levels H in PWUV zone for finding the dangerous zones, where H exceeds the maximum acceptable levels, calculations of equal potential lines H in phase cross-sections of ALs of 220-1150 kV AC and ALs of 500kV DC were made. An example of distribution of equal potential lines H in middle phase cross-section of ALs of 500 kV operating at the matched load (load power is equal to the active line power) with the value of phase current module of 1039 A is shown in Fig.5.4.

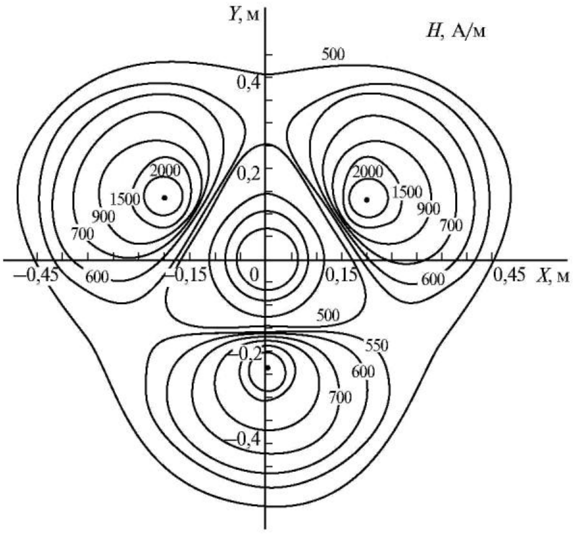

Fig. 5.4. Distribution of equal potential lines *H* in the phase cross-section of ALs of 500 kV AC. м=m; А/м=A/m

The gained data on MF intensity distribution was considered during substantiation of maximum permissible levels of MF of IF during PWUV in "Reference Impact Safe Levels of alternative MFs with frequency of 50 Hz at PWUV in ALs of 220-1150 kV" №5060-89.

5.1.2.4. Magnetic fields in PWUV zone during the short circuit

To detect the probability of additional adverse effect of MF on the person, the study of single phase short-circuit (SC) modes was conducted by the example of the certain AL of 750 kV (Kalininskaya Nuclear Power Plant – substation "Vladimirskaya" with extent of 396,8 km at the disconnected line from Kalininskaya NPP). AL phases consist of 5 wires of AS-330/43 mark with the splitting radius of 40 cm; and static protective cables consist of 2 wires of AS-70/72 mark with a distance of 40 cm between them. Line voltage of 500 kV was applied to the line from "Vladimirskaya" substation. Voltage and current in phases and cables at single phase SC of A phase at a distance of 142 km from the substation were registered at the substation "Vladimirskaya". SC peak current reaches 6 kA in the fault phase (Fig. 5.5), but the induced one in the static protective cables is 1,5 kA (Fig. 5.6). It creates MF density H at the phase wire surface of 15,2 kA/m and at the cable surface of 15.6 kA/m (peak levels).

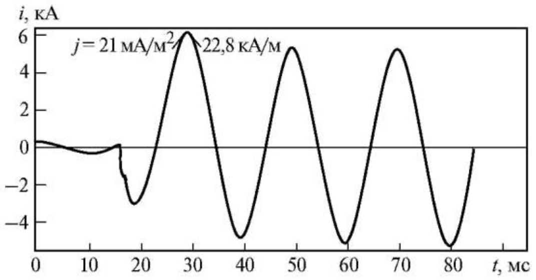

Fig. 5.5. Oscillogram of SC current in the affected phase of 750 kV AL; кА=kA; мА/м^2=mA/m^2; кА/м=kA/m; мс=ms

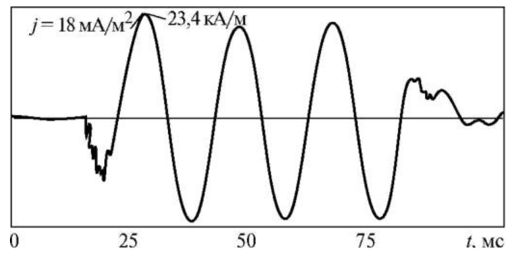

Fig. 5.6. Oscillogram of current in the static protective cable induced in the moment of single phase SC of 750 kV AL. мА/м^2=mA/m^2; кА/м=kA/m; мс=ms

In the normal mode of AL work, voltage will make 750 kV. It means that the SC current value is 1.5 times as much as the testing time. Then the peak values of H will be 22,8 kA/m at the phase wire surface and 23,4 kA/m at the static protective cables. It is 7 times as much as the maximum permissible value H, acting now in the territory of RF (3,2 kA/m) for the overall effect and 4,4 times (5,2 kA/m) - for the local impact.

But the lifetime of MF of similar density is 0,06 s, that does not allow to compare these values with the normative ones, because the last were set not for the impulse, but for the continual modes of impact. At the same time this quantity is approximately 6 times as much as the normative value H for the short-time impact (4 kA/m), offered according to the recommendations of IN-IRC/IRPA [33, 34].

Such excess puts a question on a necessity of assessment of the possible impact of these MF levels on a body of the person, considering even short-term impacts of this type. On the basis that according to state-of-the-art understanding, the effective value at the man exposure in MF is the induced current, let's consider the values of current densities, induced by MF from SC currents in the man body. It can be calculated by the equation, resulted in paragraph 5.1.1. It is the following:

$$j = \pi R \sigma f \mu\mu_0 \frac{I}{2\pi R_1}$$

where $B = \mu\mu_0 H = \mu\mu_0 \frac{I}{2\pi R_1}$; I - a current in the wire, A; R_1 - a distance from a centre of the investigated organ to an axis of the wire with current; μ - a magnetic permeability of the organ; μ_0 - a magnetic constant.

Brain and heart are the main structures, ensuring the normal activity of the organism. Brain is the closest to the wires of the phase organ of the man with the maximum tissue conductivity (0,7 Cm/m [35]). Now let's calculate the value of *j*, the induced MF, SC currents in the man brain, replacing the phase and wire cable braces under voltage at the moment of the above mentioned single phase of SC for the worst case when the man head is close to the phase or cable wire. The average brain endocasts of the man is 0,81 dm^3 [31], the average radius of the brain will make 5,8 cm. A radius of wires R_1 will be 7,5 cm for the phase wire and 7 cm for the cable wire.

Expanding to Fourier series the current curves in phase and in cable, we will get the acting values of their first harmonics (frequency of 49,9 Hz) 3860 A - for phase and 1070 A - for cable (there are practically no higher harmonics, because their contribution is below 0,5 %). According to the above-mentioned equation, let's estimate *j* in the man brain, conducting the works at AL of 750 kV: j=21 mA/m^2 -for phase wire and j=18 mA/m - for cable.

According to [35] the current density is divided into four zones according to the man's level of hazard:

1. At the current density *j* that is in limits of 1…10 mA/m^2 only minimal effects are noticed, representing no danger to the human beings.
2. At the current density *j* that is limits of 10…100 mA/m^2 the marked impacts are noticed (both visual and from the nervous system).
3. At the current density *j* that is in limits of 100…1000 mA/m^2 stimulation of the excitable structures occurs and the injurious effect on health is possible.
4. At the current density *j* exceeding 1000 mA/m^2, extrasystole, ventrical fibrillation (acute injuring effect) is possible.

So, a person working under voltage at AL of 750 kV, at the moment of SC is affected by MF, referred to the beginning of the second zone of hazard according to the current density.

At the moment of single-phase reclose (SPR) in AL phase the current occurs. An oscillogram of the current is shown in Fig. 5.7. Harmonic analysis of the phase current curve in SPR moment shows the presence of a rather large quantity of higher harmonic components.

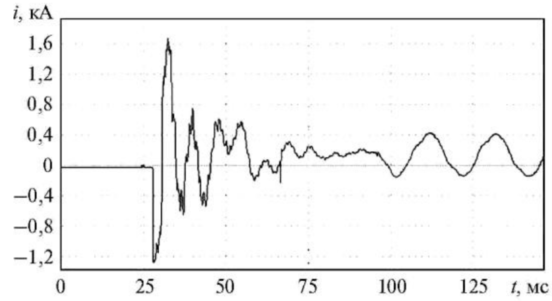

Fig 5.7. Oscillogram of the current in AL phase of 750 kV after successful SPR; мс=ms

Table 5.6 contains the results of Fourier series components calculation for the current in the line phase, occurred at the moment of successful SPR.

Table 5.6. Fourier series components for the current in phase at the moment of successful SPR.

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Fnd:	339A	210 deg	18th:	35.5%	351 deg	35th:	5.2%	2 deg
2nd:	155.2%	334 deg	19th:	9.5%	93 deg	36th:	3.0%	75 deg
3rd:	211.1%	144 deg	20th:	5.2%	202 deg	37th:	1.3%	19 deg
4th:	48.6%	269 deg	21st:	4.8%	294 deg	38th:	2.5%	58 deg
5th:	48.2%	33 deg	22nd:	4.3%	8 deg	39th:	10.7%	252 deg
6th:	23.7%	108 deg	23rd:	1.9%	14 deg	40th:	6.8%	52 deg
7th:	8.2%	108 deg	24th:	8.0%	19 deg	41st:	4.1%	108 deg
8th:	11.8%	121 deg	25th:	11.6%	184 deg	42nd:	2.3%	186 deg
9th:	10.6%	222 deg	26th:	6.4%	296 deg	43rd:	1.9%	290 deg
10th:	21.1%	14 deg	27th:	6.1%	43 deg	44th:	3.6%	2 deg
11th:	37.2%	78 deg	28th:	4.5%	103 deg	45th:	3.1%	97 deg
12th:	26.1%	238 deg	29th:	2.5%	166 deg	46th:	1.1%	18 deg
13th:	7.9%	350 deg	30th:	0.6%	254 deg	47th:	3.6%	181 deg
14th:	6.0%	65 deg	31st:	1.9%	259 deg	48th:	5.4%	321 deg
15th:	5.8%	75 deg	32nd:	12.6%	32 deg	49th:	4.9%	55 deg
16th:	8.4%	112 deg	33rd:	7.7%	156 deg	50th:	2.8%	144 deg
17th:	19.0%	153 deg	34th:	6.0%	284 deg			

Frequency: 49.9 Hz

Each component of the current creates MF. It induces the current in the human brain and its density can be calculated, using the above-mentioned equations.

A histogram of the acting values of Fourier series components for the current density *j*, induced in the human brain at the moment of successful SPR, is shown in Fig. 5.8.

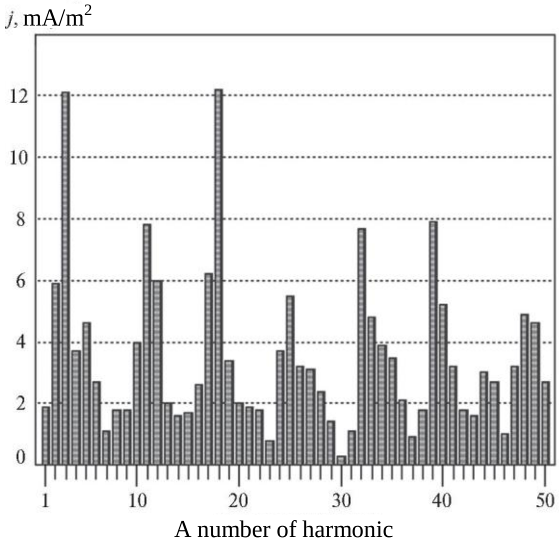


Fig. 5.8. A histogram of the acting values of Fourier series components of the current density j in the human brain.

In Fig. 5.10 an oscillogram of the current, induced in the static protective cable at the moment of SPR is shown and in Fig. 5.11 a resulting curve of the current density, induced by MF of the static protective cable current in brain of the man, who works under voltage (for example, replacement of static protective cable braces), is given.

As it can be seen from Figs. 5.9 and 5.11, in separate intervals of time the current densities, induced in human brain, can exceed 100 mA/m^2: for phase and cable wires in the test mode - 121 and 77 mA/m^2, accordingly, and in the operating mode of AL of 750kV - 181,5 and 115,5 mA/m^2.

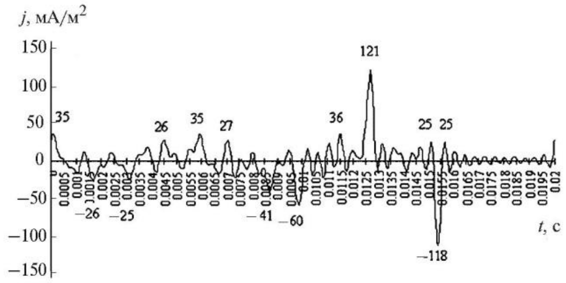


Fig. 5.9. A curve of the current density *j* in the brain of the man who works under voltage at the line phase at the moment of successful SPR; мA/м^2=mA/m^2, c=s.

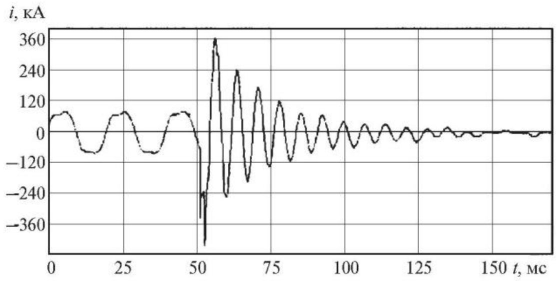


Fig. 5.10. An oscillogram of the current in the static protective cable of AL of 750 kV after successful SPR; кA=kA, мс=ms

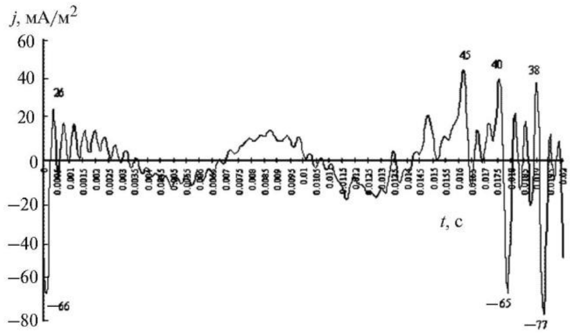


Fig. 5.11. A curve of the current density *j* in the brain of the man, who works under voltage at the static protective cable of the line at the moment of successful SPR; мA/м^2=mA/m^2

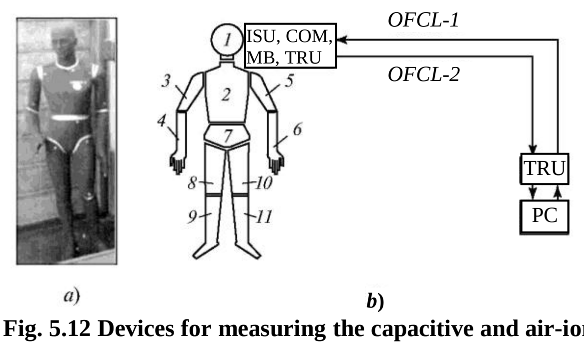


Fig. 5.12 Devices for measuring the capacitive and air-ionic currents in any parts of a human body (a) a model of the vertically standing person MVSP-1 (*a*), MVSP-4 (*b*)

So, the test results proved that at SC moment the current density *j* is in a zone area of the marked effects. At SPR moment, the current density *j* is in a zone of the excitable structure stimulation. SC current depends on resistance of the SC loop. The maximum estimated values of SC currents reach 20…30 kA for the AL net of 500 kV (acting values), at that time *H* and *j* values can be 5…6 times more. At SPR moment a value and a form of the phase current depends on AL voltage, its parameters (inductivity, capacity, resistance etc, for different line constructions this parameters are different) and on its characteristics of switcher arc at the moment of its switching on. Inductivity of 1150 kV AL is 1,5…1,8 times less than of 750 kV AL, its capacity is 1,3…1,7 times higher, and at ALs of the same voltage class, the air switches with more partitioning of the arc break zone are used. Then for ALs of 1150 kV the peak values of *j* can be 2 or 3 times higher than for ALs of 750 kV at successful SPR. Along with this, at SC moment at the line of 1150 kV *j* transfers into the zone of the marked effects, and at SPR moment it approaches the zone of the damaging action. Availability of the stationary complex of adverse factors of the working environment at conducting the works under voltage and conditions of the increased danger during the work at height, considered by itself as a factor of risk, allow to assume that currents induced in the human brain by impulse MF, occurring at successful SPR, can result in increase in the risk extent of break-down and can be of additional danger for a person.

5.1.2.5. Phantom measurements of capacitive and air ionic currents in body parts of the human, being in EF of IF

Estimation of EF intensity distribution over the human body of a man, being under AL of super voltage or in territory of open switchgear (OSG) of substation is rather complicated and not exact enough, moreover, if this estimation is to be made for the person, wearing a protective suit. It is also complicated to make a mathematical model and estimate the electromagnetic radiation (EMR) of corona discharge (CD), all the more to estimate the distribution of its parameters over the human or animal body. In such cases the application of phantom measuring methods is reasonable. It means conducting measurements at the models of a person or an animal, made of actual size and placed in real or close to real EF or in a zone of EMR sources.

Devices for measuring of capacitive currents in some parts of a human body are made in a form of phantoms (models) of vertically standing person (MVSP-1 and MVSP-4) of the actual size (Fig. 5.12).

MVSP-1 device is intended for measuring the capacitive currents in the human body of a man being on the ground potential. It has two coating layers made of brass foil and electric conductive epoxy paint with conductivity of the average one of the human body. Coating layers are divided into ten zones of measuring (Fig. 5.12 (a)): a head, a body, right and left shoulders, forearms of left and right arms, a pelvis, a right foot, a thigh bone of the left foot and a shank with the leg of the left foot. The device is equipped with the remote control block with dancer showing the measuring results. It was used for checking the shielding properties of the person's suit, defending from EF effect.

MVSP-4 device intended for measuring the capacitive and air-ionic currents in body parts of the man who works under voltage of ALs of super voltage. A surface of the MVSP-4 is divided into 11 zones of measuring (Fig. 5.12(b)). MVSP-4 is equipped with the independent supply unit (ISU), a commutator (COM), a measuring block (MB) and also with a transmit-receive unit (TRU) of digital information passing through the optical and fiber communication lines (OFCL), used to control the measuring processes and receiving of the measuring results at the computer, set on the ground potential. OFCLs are not only communication lines, but they are also an insulating cell between MVSP-4, located on the phase potential of AL super or ultra high voltage, and the computer, set on the ground potential.

In each measuring zone 84 measurements in 0,02 s with the next expanding to Fourier harmonic series, are made. In Table 5.7 the results of measurements of the air-ionic currents (constant component of the current) and the capacitive ones (the first harmonic of 50 Hz frequency) in the body parts of a man, being without any protective means in a zone of conducting the works under voltage (on the phase) at AL of 500 kV, are shown. In Table 5.8 there are the measuring results of the same currents, but in case when MVSP-4 device is clothed in the protective suit (without gloves and shoes).

Table 5.7. **Air-ionic and capacitive currents in body parts of a man, being on the phase of 500 kV AL without the protective suit.**

Number of a zone	Constant component, μA	The first harmonic (50 Hz), μA
1	-53,7	242,7
2	-88,2	197,5
3	14,5	98,7
4	167,3	494,3
5	21,5	65,1
6	-96,1	223,9
7	42,7	197,3
8	-156,1	185,7
9	121,2	949,2
10	21,2	159,2
11	-212,5	647,4

Table 5.8. **Air-ionic and capacitive currents in body parts of a man, being on the phase of 500 kV AL in the protective suit.**

Number of a zone	Constant component, μA	The first harmonic (50 Hz), μA
1	0,8	0,9
2	1,2	4,9
3	0,9	0,9
4	12,2	35,8
5	0,6	0,7
6	1,6	4,7
7	1,2	0,6
8	0,5	0,6
9	-0,3	4,6
10	0,7	0,5
11	4,0	46,9

At AL of 500kV in a zone of conducting the works under voltage, the air-ionic currents are comparative to the peak values of the capacitive currents IF and make 15…84% of the last ones. Wearing the protecting suits results 16 times reduction (right hand shoulder) and 294 times reduction (thigh bone of the right foot) of the current values of air ion (not considering the zones with no protected areas).

The capacitive currents of IF weaken much more in comparison with the air ion currents: 41 times (body) and 313 times (pelvis area). The gained results confirm an assumption of occurrence of not only EF, MF and capacitive currents of IF, but also of air ionic currents in a zone of conducting the works under voltage. These results also show a high efficiency of the protective suits, protecting the workers from capacitive and air ionic currents that caused an absence of the necessity of their additional regulation at conduction of the works under voltage when it's required to use the protective suits.

5.1.2.6. Phantom measurements of distributing the intensity of EF of IF over the human body surface

Intensity *E* of EF was distributed over the human body with the help of MVSP-2 and MVSP-3 devices. The devices are made as phantoms of the vertically standing person of the actual size and are reinforced inside by the glass cloth coating with epoxy resin and have two outside coating layers, made of aluminum foil and electroconductive paint.

MVSP-2 device is intended for measurements, conducted in the field conditions and equipped with 82 capacitive electric sensors, set in acupuncture points (Fig. 5.13, b), built-in individual supply unit, communication and measuring systems, and also a block of digital indication of the measuring results, fixed on the back of the device. This device is shown in Fig. 5.13 a. The measuring process control is automatic. The device was used to measure the distribution of intensity *E* of EF over the body surface at the working places at substation and line personnel, and also to test the shielding properties of the suits, protecting the personnel from EF impact. In Fig. 5.14 a block diagram of the system of EF intensity measuring on the surface of MVSP-2 phantom device is shown. In the invalid condition each measuring electrode is connected with the conducting surface of MVSP-2. In process of measuring with the help of i-electrode, the last is connected through the commutator to the input resistor R_{in} of the amplifier. The resistor is connected to the conductive surface of MVSP-2. The measuring signal from the amplifier is applied to A to D converter (ADC), from ADC – to the display unit. In parallel with this a number of the electrode is transmitted from the commutator to the display unit, and from the amplifier a number of measuring limit is transmitted.

The display unit is on the back of MVSP-2. A number of the measuring point, the active value of the measuring current (nA) and a number of the measuring limit is read at the display unit.

The device consists of four measuring limits. Every limit is matched by its factor, multiplied by the measuring value of the current, shown at the display unit. The factors 1, 4, 20 and 100 correspond to the limits 1, 2, 3, and 4 (Fig. 5.15).

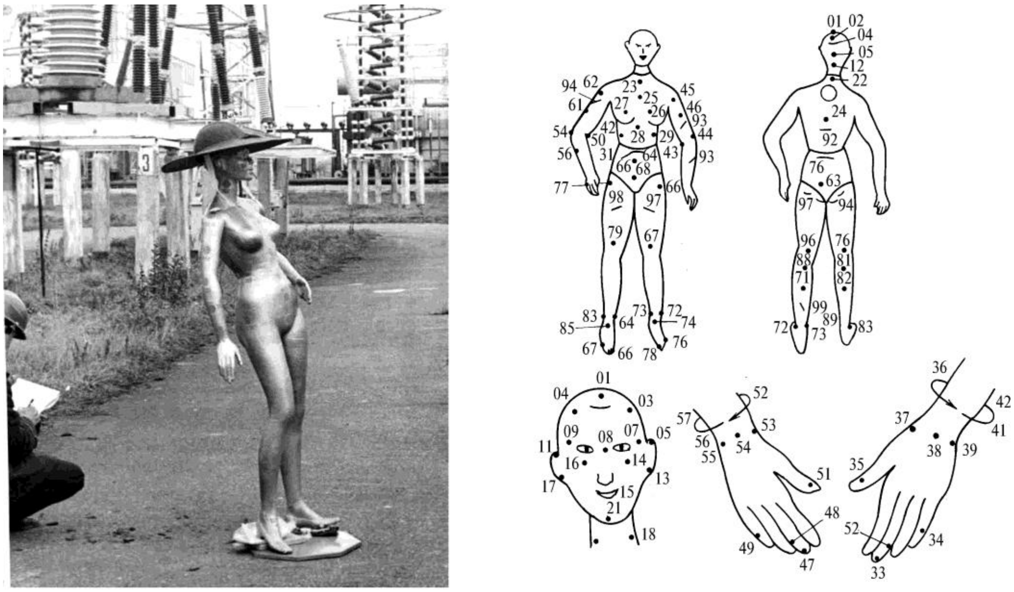
The active value of EF intensity *E* in each measuring point is estimated according to the equation:

$$E = \frac{I}{2\pi\varepsilon_0 f S_{el}}$$

where I is an active value of the measuring current; S_{el} is a square of the measuring electrode surface; f is a current frequency (50 Hz); ε_0 is the electric constant.

MVSP-3 device (Fig. 5.16) is intended for measuring the distribution of EF intensity *E* over the human body in laboratory conditions. It is equipped with 64 capacitive measuring sensors, a supply unit of 220 V, built-in communication and measuring systems and also with a system of input-output information, connected with the computer, where the measuring process is controlled and the measuring results are processed.

MVSP-3 device was used for bench test of the shielding properties of the suits, protecting the person from EF impact.



a) *б*)

Fig. 5.13. MVSP-2 device at the open switchgear of 750 kV at “Bely rast” substation (a) and a scheme of the measuring electrodes distribution over the surface of MVSP-2 device (b)

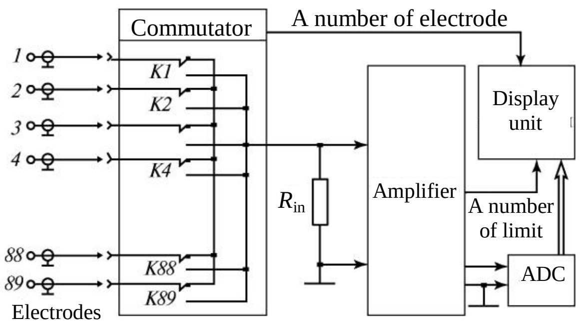


Fig. 5.14. A block-diagram of EF intensity measuring system at the surface of the phantom device

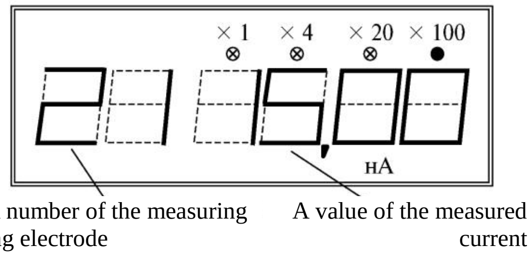


Fig. 5.15. The display unit of MVSP-2 device

In Table 5.9 the sample results of *E* measurements over the surface of MVSP-2 device, set at the path of the open switchgear of 750 kV substation, are shown. MVSP-2 device measures the capacitive current, flowing through the measuring electrode with the normalized surface area. Further the current is converted to EF intensity *E*.

Measurements showed that at intensity of the undistorted EF at a level of 1,8 m above the ground, equal to 17 kV/m, the intensity over the body surface of MVSP-2 was changing from 2,8 kV/m (breast) to 243 kV/m (tip of nose).

So, the results of measurements show significant differences in levels of the distorted EF at the surface of the human body and testify about the possibility of EF local effects on condition of the undistorted field, being below the standards. These data was used at development of “Sanitary standards and rules of conducting the work on conditions of effecting of alternative electrical fields of the industrial frequency (50 Hz)” № 58021 and in process of development of a concept of the unified principle of standardization of electrical and magnetic components of IF EMFs.

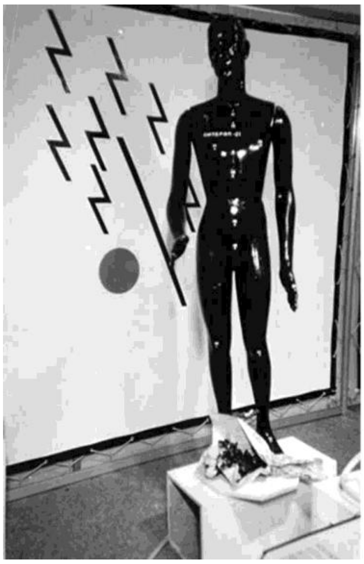


Fig. 5.16. MVSP-3 view

Table 5.9. **The sample results of *E* measurement over the surface of MVSP-2 device, set at the open switchgear of “Bely rast” substation of 750kV.**

A number of point	S_{el}, cm^2	*I*, nA	Measuring limit	*E*, кV/m
1	1	10,00	2	143,87
5	1	6,40	2	92,07
8	1	4,71	2	67,76
11	1	8,01	2	115,24
15	1	3,38	3	243,14
18	9	9,38	2	14,99
24	9	7,00	3	55,95
25	9	7,06	1	2,82
32	1	10,40	2	149,62
51	1	4,44	1	15,96
68	9	4,50	2	7,19
75	1	12,00	1	43,16
84	9	3,58	3	28,61

5.1.2.7. Phantom measurements of electromagnetic corona discharge

A special stand was made for studying EMF corona discharge effects on the living organisms. The working elements of the stand are acicular and grounded electrodes (AE and GE). D. C. voltage of ±75kV is applied to AE, and on GE experimental animals (mice), being under the effect of high DC voltage, are placed. EMR intensity of corona discharge of the spread spectrum is measured by a phantom of the mouse, set on the GE (Fig. 5.17). The phantom has a metallic coating, connected with the GE through a ballast resistor R_b.

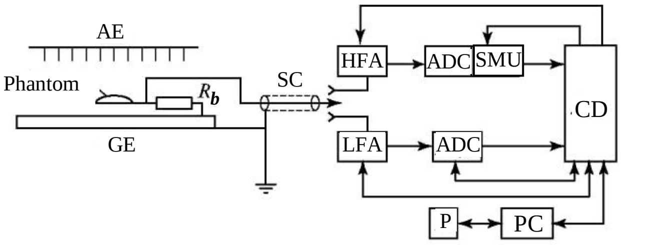


Fig. 5.17. A stand and a block-diagram of corona electromagnetic radiation measuring

The measuring signal is applied from the resistor R_b via the screened cable (SC) into the measuring system. This system consists of high-frequency (HF) and low-frequency (LF) channels. The low-frequency channel works in the frequency range of 0 to 200 Hz and consists of a low-frequency amplifier (LFA) and A to D converter (ADC), the digital signal from which enters the computer (PC) and printer (P) via the conjugation device. The low-frequency channel allow to carry on 84 measurements in 0,02 s. High-frequency channel works in the frequency range of 200 Hz to 10 MHz and consists of a high-frequency amplifier, ADC, a satellite memory unit (SMU), connected to the computer via the conjugation device (CD). High-frequency channel carries on 4096 measurements in 0,005 s.

In Figs. 5.18 and 5.19 examples of volt-second intensity characteristics at the mouse phantom, applying a voltage to AE of +75 kV and -75 kV, accordingly, are shown.

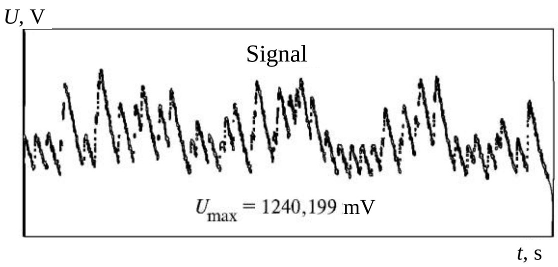


Fig. 5.18. A Volt-second characteristic of voltage, induced at the mouse phantom of corona discharge DC EMR at AE voltage of +75 kV

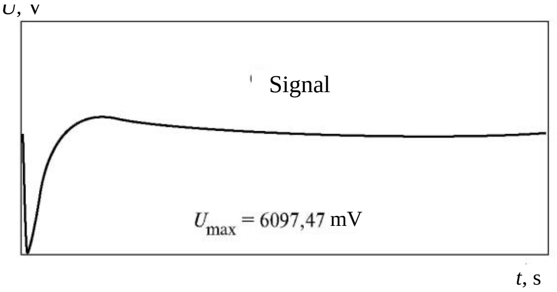


Fig. 5.19. A Volt-second characteristic of voltage, induced at the mouse phantom of corona discharge DC EMR at AE voltage of –75 кВ

In Fig. 5.20, *a* and *b* the rated (according to the data from Figs. 5,18 and 5,19) curves of peak-frequency spectra (PFS) of intensity *E*, DC corona discharge created by EMR at the mouse surface are presented. These curves are gained as a result of conversion to EF intensity with its further expanding to Fourier integral, using fast Fourier transformation (FFT).

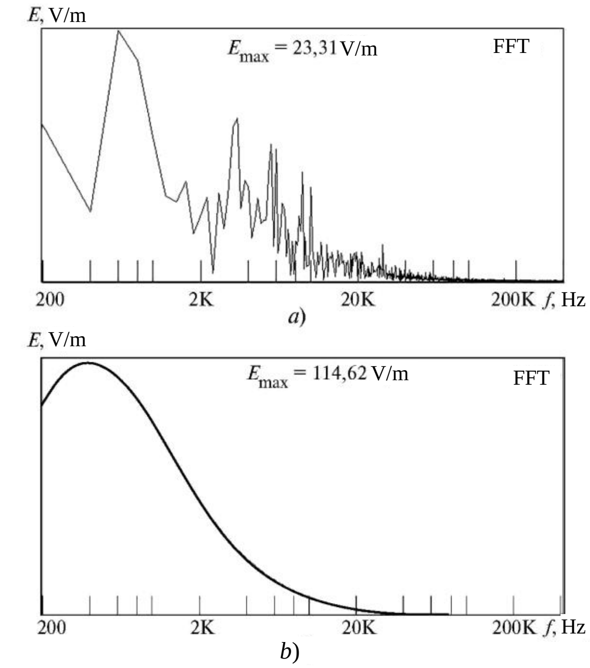


Fig. 5.20. Amplitude and frequency spectrum of EF intensity at the mouse phantom, DC corona discharge induced by EMR at AE voltage of +75 kV(a) and -75 kV (b)

At the positive polarity of voltage at AE, the power surges, induced by EMR corona discharge at the mouse phantom, are very often, and the peaks are in the limits of 200…1500 mV. At the negative polarity the power surges are rather seldom, but their peaks have the greater values: 500…7000 mV.

A form of the curve of PFS *E* is complicated at the positive polarity and the amplitude maximums of *E* reach 10…50 V/m at frequency of 0,5… 1,0 kHz. At the negative polarity the amplitude maximums *E* reach 50…200 V/m at frequency of 300…800 Hz. For both polarities the amplitudes of *E* decays at the frequency of 100 kHz and more.

The obtained data testifies that EMR of corona discharge spread spectrum by its spectral characteristics is similar to the ones which are available at the working places of PC users. It requires a special attention, particularly, in elimination of the adverse effect on the person.

5.1.2.8. Instrumental methods of estimating the levels of electric and magnetic fields of the industrial frequency at the working places of personnel of electric grid objects

For the acting sources, EMF levels are controlled, mainly, by instrumental measurements. So, “Guidelines for estimating electromagnetic fields of air high-voltage power lines and hygienic requirements for their location” №4109-86 define both parameters of sanitary and protective zones of air power lines of 330 kV, 500 kV, 750 kV and 1150 kV and recommendations for conducting instrumental measurements in limits of sanitary and protective zones.

Nevertheless, simple registration of EF and MF IF levels at the places of personnel work can’t give the objective picture of intensity and time parameters of influencing factor on the personnel. In actual conditions for hygienic assessment of EF and MF IF, both the methods of estimating the time period (according to SanPiN 2.2.4.1191 – 03) and the measuring procedure in zones of location of air power lines of EF and MF IF at the places of personnel work are used rather seldom, since during operation and maintenance of electric plants the working places are not fixed, and during the working shift the certain worker (or a group of workers) moves in the work performance zone. This question acquires the special importance at certification of the working places, because according to requirements R 2.2.2006-05 "Manual for hygienic assessment of the factors of working environment and working process. Criterias and classifications of the working conditions" it is necessary to establish a class and a degree of hazard of the working conditions in relation to their adequacy to hygienic regulations.

In the State Institution the Research Institute of occupational health of RAMS the system of hygienic assessment of intensity and time parameters of EF and MF impact on personnel, working at the open switchgear and AL, was developed and approved. The system allows to make a rather adequate estimation of an exposure degree of different categories of workers to the factor and to compare these values with the appropriate hygienic regulations. The system of hygienic assessment of EF and MF IF levels at the open switchgear of super voltage is created on the basis of measuring the levels of electric and magnetic components at all the possible places of personnel work (in all the cells of equipment), on data professional activity character of the separate working groups and on chronicle investigations.

In order to estimate the levels of EF and MF IF at the ground working places of line personnel (operating the super voltage AL), the standardized scheme of measurements was designed. This scheme allows making hygienic assessment of EF and MF levels in run of AL in limits of sanitary and protective zones in 35 points (measuring sites) (Fig. 5.21). On the basis of measuring results, a matrix of EF and MF IF levels distribution is created. After that, the hygienic assessment of EF and MF levels, like for the open switchgear, is made, based on data, relating to a character and activity categories and also timing investigations.

It should be especially noted in process of registration of MF IF levels, data on loading levels at the appropriate sites of electric networks, is requested. The data is analyzed by considering a loading part of the nominal load (maximum rated) at the moment of measuring.

Based on the measuring results, a graph (histogram) of EF and MF distribution is drawn (for the open switchgear and AL, accordingly), the average weighted values of EF and MF IF (*E* and *H*) are estimated for the each electric grid object.

"Exposure loadings" as a main criterion of factor impact degree on the working staff from correspondent professional groups is defined on the basis of intensity and intensity-time characteristics of EF and MF IF effects. It is realized by conversion of the obtained average weighted values of *E* and *H* to the reference estimated exposure loadings: in every working shift and in a year, considering a number of the working shifts for each working group. The received data are converted to the reference averaged "loading" for each working group per day and per hour. Calculations are conducted using the following equation:

$$EH_E = \frac{E_{\text{av. weighted}} TN}{365 \cdot 24},$$

$$EH_H = \frac{H_{\text{av.weighted}} (I_{\max} / I_i) TN}{365 \cdot 24}$$

where EH_E is the EF exposure load; EH_H is the MF exposure load; $E_{\text{aw.weighted}}$ is an average weighted value of EF intensity at the open switchgear or in AL zone; $H_{\text{aw.weighted}}$ is an average weighted value of MF intensity at the open switchgear or in AL zone; T is an average working time during the shift; N is a number of working shift per year; 365 is a number of days per year; 24 is a number of hours per day; I_{max}/I_i is a ratio of the maximum operational current to the current of electric plant at measurements.

At EMR analysis at the places personnel work, maintaining the open switchgear and AL, a part of the measuring sites with a certain level of EF intensity is estimated by "step" of 1 kV/m and MF intensity - by "step" of 1 A/m.

As an example, the measuring results of OSG of 500 kV in limits of sanitary and protective zones of 20 runs of 500 kV AL that are in the European territory of RF, could be brought. Measurements were conducted at the height of 1,8;1,5 and 0,5 m above the ground and are shown, considering the stationary means of protection at OSG.

So, based on the results of EF and MF IF level measurements at OSG in 350 points from the diagram of EF and MF IF intensity distribution (Fig. 5.22) one can see that a part of the measuring sites with the levels up to 5 kV/m (not requiring any restrictions on time of staying during the shift) is about 21 % of the working places, with the levels of 5 to 20 kV/m - about 73,6% and with the levels of more than 20 kV/m (where it's prohibited to stay more than 10 minutes) - only 5,4 % of the working places. By this, the working places, requiring use of protective means with the levels of more than 25 kV/m, were not revealed. However, estimation of the average weighted value of EF IF intensity for this OSG of 500 kV showed that it is 10,7 kV/m, greatly exceeding the level of 5 kV/m that allows performing the works without any staying time limitations.

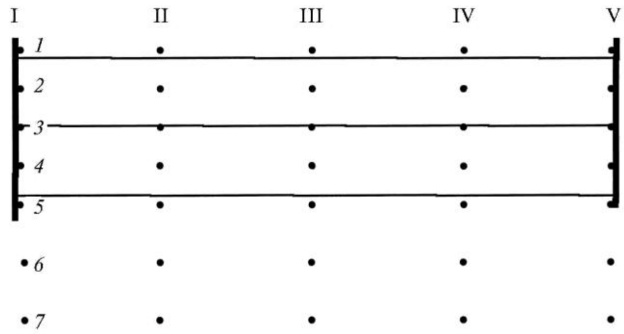


Fig. 5.21. A scheme of conducting the measurements of EF and MF IF levels in the limits of sanitary and protection zone of ALs

According to the measuring results of MF IF intensity levels that were carried on at the load of 25 % of the nominal one, one can see (Fig. 5.22) that in the most cases (81,4%) the registered levels did not exceed 5 A/m. These levels are significantly lower than the maximum permissible levels for industrial impact conditions. The average weighted value of the measured MF intensity was 4,6 A/m. However, considering that measurements were carried out at the load of 25% of the nominal one, the received value should be multiplied by 4 for an adequate hygienic assessment of possible MF levels at the working places. Accordingly, the average weighted value of MF IF intensity will be 18,6 A/m for this OSG (that is also lower than MPL for industrial impact conditions).

The measured levels of EF and MF IF intensity show a high degree of the received data coincidence with the rated ones in limits of sanitary and protective zones of 500 kV AL. They also allow calculating the average weighted value of EF and MF IF intensity for ground working places of line personnel, maintaining these power objects.

An estimation of the average weighted value of EF IF intensity showed that it is 8,8 kV/m for ground work conditions in a range of sanitary and protective zones of 500 kV AL. The estimated weight-average MF intensity level showed that it is 3,7 A/m for load conditions of 25% of the nominal one, that is for an adequate hygienic assessment it should be calculated, that the average weighted value of MF IF intensity at the working places of line personnel, maintaining AL of 500 kV should make 14,8 A/m. Reference dosimetry - an estimation of the exposure load, carried out for different groups of personnel, operating and maintaining substation and AL of 500 kV, considering the time parameter (table 5.11), testifies that line service and repair service personnel of substations is, at the greatest extent, affected by EF and MF IF. Relay protection and automatic service personnel is exposed to EMF IF two times less than line service and repair service staff. But the exposure load of dispatch service personnel is 4 times less than line service and repair service staff.

A comparison of the obtained data with results of the similar estimation for working conditions shows that the reference EF IF exposure per hour a year should be less than 1,02 kV/m, but by magnetic component should be less than 16,4 A/m, meeting normative requirements for the whole working day for EF at a level of 5 kV/m (8 hours a day) and for MF – 80 A/m.

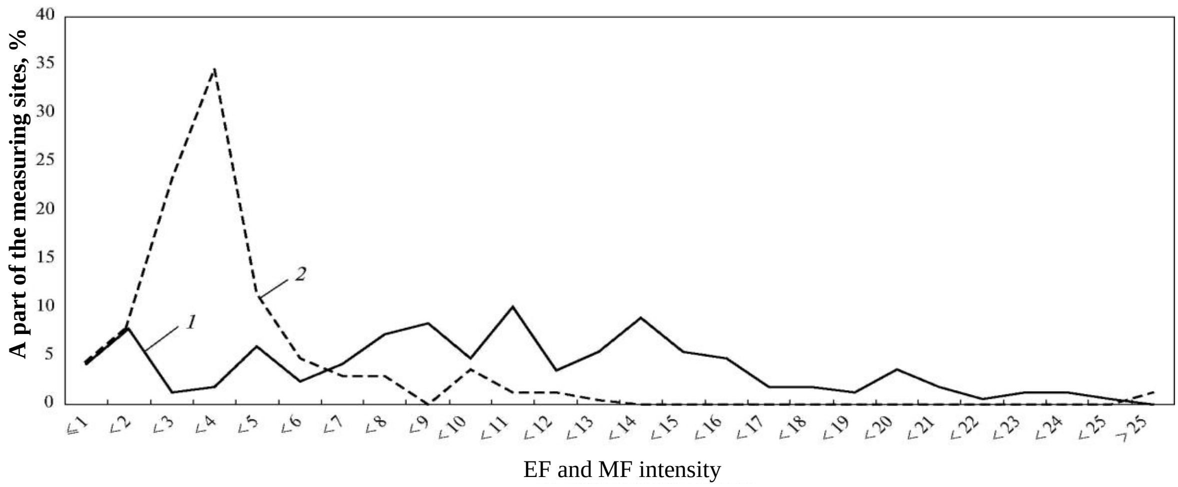


Fig. 5.22. The shared distribution of EF and MF IF levels at OSG of 500 kV: 1 - intensity of EF, kV/m; 2. Intensity of MF, A/m

Table 10. **EF and MF IF intensity levels at the limits of sanitary and protective zones of 550 kV AL (kV/m; A/m)**

Parameter	Measuring sites (according to the scheme from Fig. 5.21)					
		I	II	III	IV	V
Intensity of EF of 50 Hz, kV/m $\frac{E_{av.}}{E_{min}...E_{max}}$	1	1,5 / 0,5...3,0	4,5 / 1,3...5,7	6,8 / 1,3...3,7	4,4 / 3,6...11,0	1,4 / 1,0...2,1
	2	1,1 / 0,1...3,6	3,1 / 2,5...4,5	5,4 / 3,9...8,0	4,2 / 3,6...5,0	1,0 / 0,5...3,5
	3	0,4 / 0...1,1	3,3 / 0,7...5,7	6,8 / 2,7...8,0	3,0 / 1,5...10,0	0,4 / 1,0...2,0
	4	1,1 / 0,5...2,9	3,4 / 1,5...6,7	5,3 / 4,0...8,0	3,1 / 2,3...9,0	0,7 / 0,5...1,5
	5	1,3 / 0,7...3,0	4,8 / 0,5...6,5	7,0 / 2,2...14,0	6,7 / 2,4...10,0	1,3 / 0,5...1,7
	6	1,4 / 0,4...2,0	3,4 / 0,9...7,0	3,5 / 1,1...4,8	3,1 / 1,5...4,8	1,7 / 0,4...2,9
	7	1,4 / 0...2,8	1,1 / 0...3,0	1,2 / 0...1,7	1,4 / 0...1,7	1,3 / 0...1,7
Intensity of MF of 50 Hz, A/m $\frac{H_{av.}}{H_{min}...H_{max}}$	1	1,6 / 0,27...3,6	2,1 / 0,48...2,8	3,9 / 0,54...4,64	2,2 / 0,67...3,6	1,7 / 0,44...3,04
	2	1,5 / 0,24...3,04	3,5 / 0,46...5,2	5,8 / 0,2...7,04	1,6 / 0,54...2,72	1,5 / 0,32...2,96

	3	1,7 0,16...3,04	3,8 0,40...5,2	5,2 0,42...5,6	3,1 0,48...4,16	1,7 0,32...3,04
	4	1,4 0,16...2,0	3,3 0,34...4,8	5,4 0,30...5,6	1,6 0,38...2,8	1,7 0,24...4,0
	5	1,2 0,48...1,76	1,9 0,26...2,88	3,8 0,32...4,64	3,2 0,35...4,64	1,8 0,24...4,0
	6	0,3 0,2...1,68	0,8 0,24...2,4	0,9 0,16...3,2	0,5 0,40...1,68	0,3 0,24...0,88
	7	0,2 0,14...1,76	0,5 0,24...1,6	0,4 0,16...0,8	0,5 0,22...1,68	0,3 0,16...0,8

Table 5.11. The estimated **values of exposure load for electric and magnetic components of EMF IF of different personnel groups, maintaining substation and AL of 500 kV**

A group of personnel	Parameter	Average weighted value	Exposure load			
			per shift	per year	per 24 h in a year	per h in a year
Line	*E*, кВ/м	8,1	60,6	10 718,4	29,4 49,39	1,22
	H, А/м	14,8	103,6	18 026,4		2,06
Repair service of substations	*E*, кВ/м	10,7	64,2	11 170,8	30,6 53,20	1,27
	H, А/м	18,6	111,6	19 418,4		2,21
Relay protection service	*E*, кВ/м	10,7	26,75	4 654,5	12,75 22,17	0,53
	H, А/м	18,6	46,5	8 091,0		0,92
Operations and dispatch	*E*, кВ/м	10,7	16,05	2 921,1	8,0 13,91	0,33
	H, А/м	18,6	27,9	5 077,8		0,58