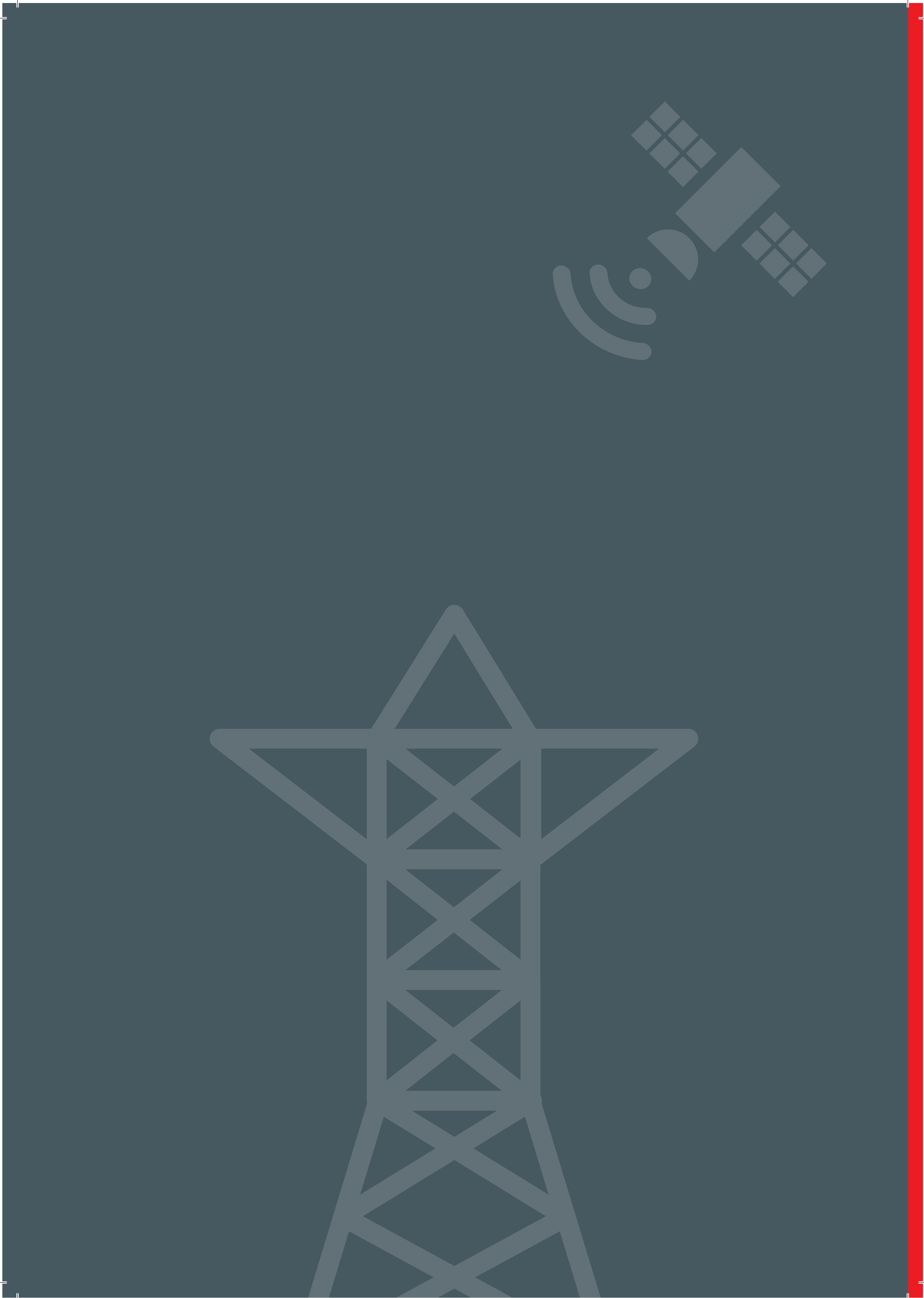
Electric and Magnetic Fields



Electric and Magnetic Fields

Electric power transmission network facilities and devices, as well as the devices connected to the electric power transmission network, all produce electromagnetic fields (EMF), more specifically, low frequency electric and magnetic fields that spread in the natural and living environment. These fields accompany the use of electric power, without which we can no more imagine our everyday life.

The Milan Vidmar Electric Power Research Institute deals mostly with technical aspects with regard to low frequency electric and magnetic fields, by measuring and calculating field magnitude as well as establishing the conformity with environmental and other legislation in this area. We also follow standpoints provided by the scientific community in protection of people against electromagnetic fields.

Did you know ...

- That electromagnetic fields are a part of the natural and living environment, where humanity has lived since its beginnings? We are exposed to the Earth's magnetic field, visible light, UV-rays, cosmic radiation from space, the radiation of radioactive elements in the ground and more.
- That besides electromagnetic fields of natural origin, humanity started causing electromagnetic fields of technical origin with the development of electrification (approx. 150 years ago)?
- That electromagnetic fields inside electrical and electric power devices indirectly enable the operation of these devices (e.g. transformers, generators, motors ...)?
- That electromagnetic fields spreading in the natural and living environment around devices are not always only an inevitable by-product of operation but are sometimes even the basic purpose of device operation (e.g. mobile phones, radars, RTV transmitters ...)?
- That electric field concept was first introduced by the English scientist Michael Faraday (1791–1867), who contributed significantly to science, especially in electromagnetics and electrochemistry areas?

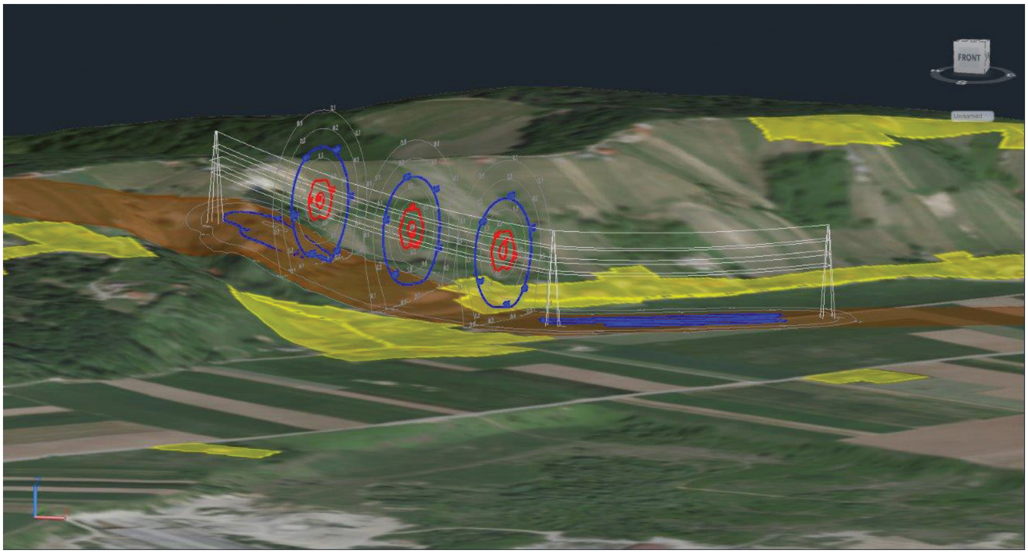


Figure 1: *Presentation of a detailed micro location calculation of the electric field at three perpendicular planes along the overhead line axis.*

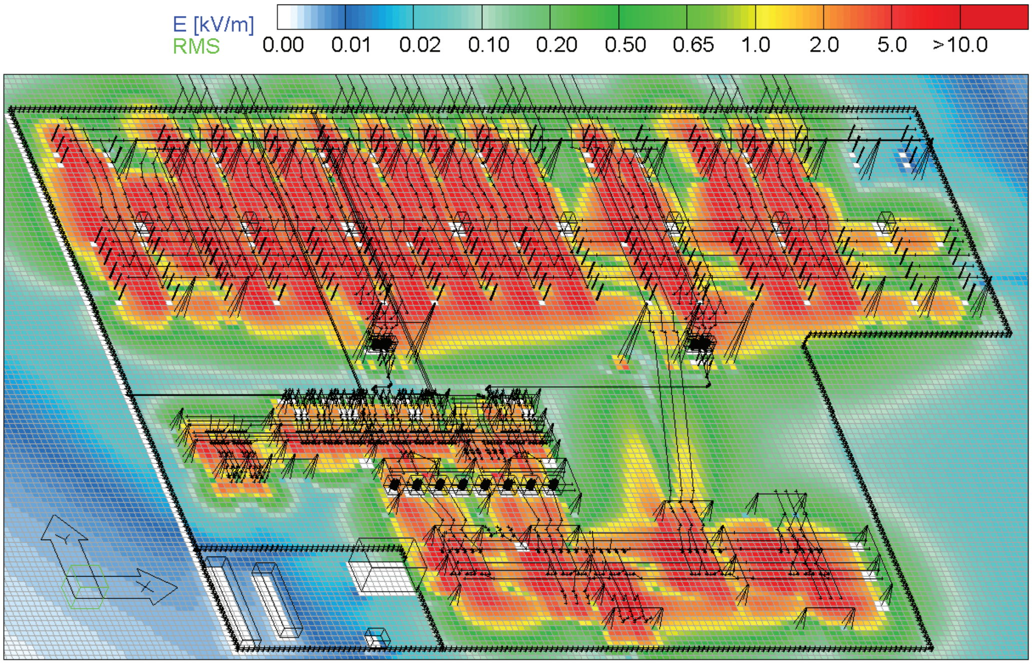


Figure 2: *Presentation of a detailed calculation of the electric field of a power substation one metre above ground.*

1 Definitions: electric field and magnetic field

The entire electric power transmission network in Slovenia and across Europe operates at a rated (network) frequency of 50 Hz (in the USA or Canada, it operates at 60 Hz). This is the nominal frequency of the harmonic time-varying of electric voltage and current in the electric power transmission network devices, as well as of the time-varying of the electromagnetic field in the vicinity of these devices and facilities. The electromagnetic field of the network frequency is in the electromagnetic spectrum (Figure 3) in the non-ionised radiation area, i.e. among the so-called low frequency electromagnetic fields or electromagnetic fields of extremely low frequencies that encompass the frequency area up to 300 Hz. At such frequencies, we usually do not speak about the electromagnetic field, but we distinguish between **electric field** and **magnetic field.** Electric and magnetic fields are not considered co-dependably, but separately.

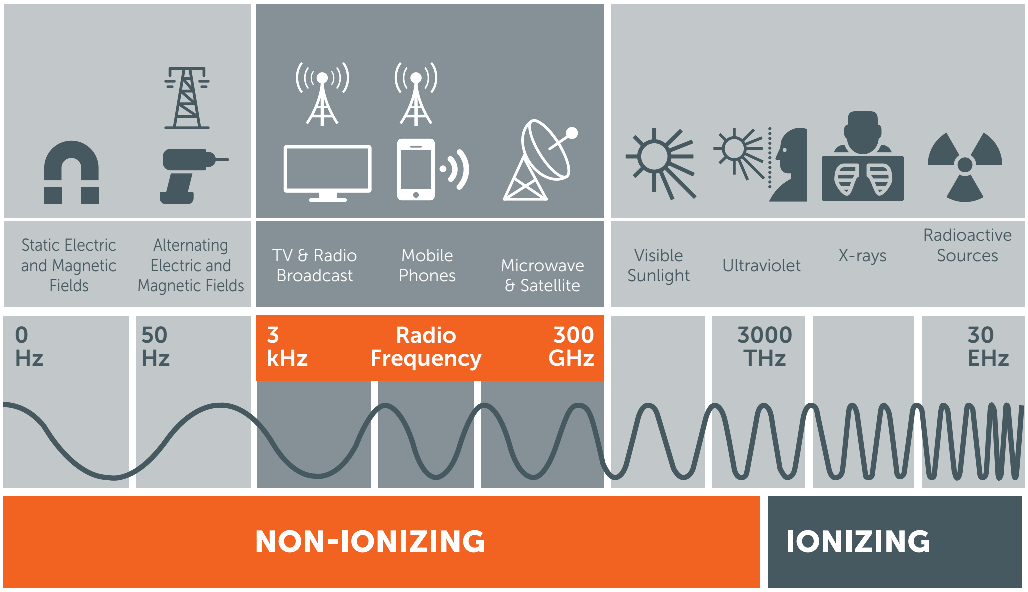


Figure 3: *Electromagnetic spectrum.*

An electric field is a field that surrounds electric charges. The electric field is conditioned with the presence of electric charge on conductors or indirectly via the electric voltage of conductors to the ground. The values of vector quantities increase simultaneously with the increasing voltage. The vector quantity that is most frequently indicated for an electric field is the electric field strength E that is measured in volts per metre (V/m).

A magnetic field is a quantity that describes the magnetic influence at a given point due to nearby electrical currents and magnetised materials. A magnetic field surrounds and is created by magnetised material and by electric charges in motion. A magnetic field increases with the intensity of electric current. The most frequently used quantity for magnetic field is the magnetic flux density *B* that is measured in teslas (T). The field values are usually given in a unit a million times smaller – the microtesla (μT).

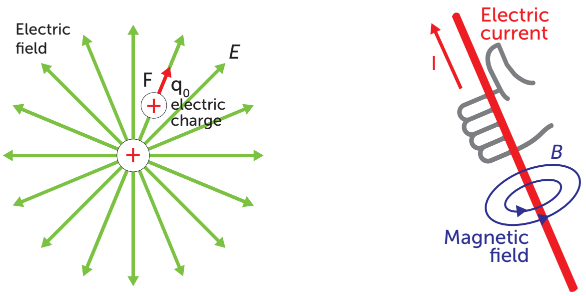


Figure 4: *Presentation of electric field and magnetic field.*

Let's repeat

- Electric and magnetic fields are present everywhere where electricity is used.
- An electric field:
  - emerges due to electrical voltage on the conductor
  - vector quantity: electric field strength *(E)*
  - unit: V/m (volt per metre)
- Magnetic field:
  - emerges due to electrical current on the conductor
  - vector quantity: magnetic flux density *(B)*
  - unit: T (tesla)

2 The sources of electric and magnetic field

2.1 Sources in the domestic ambient (household)

The source of electric and magnetic field at home include home electrical wiring and all electric energy consuming equipment (electrical devices, apparatuses, lights, including connecting cables). The CE mark for electrical devices assures the conformity with European standards.

Electrical devices cause low frequency magnetic field only while operating – when the electric current runs through the installed elements such as heating elements, motors, transformers and coils, power supply connections. In general, in households they only cause electromagnetic fields on micro locations. The highest magnitudes are immediately near the surface of an electrical device as the source of electromagnetic field; field magnitudes usually decrease quite intensively as the distance from the device rises.

Many devices which we use in the household on an everyday basis can cause very high low frequency magnetic field magnitudes on their surfaces – especially shaver, hairdryer, mixer, iron, electric stove, electric tools. The field to which we are exposed while using and being around such devices is quite non-homogeneous, meaning that only one part of the body is usually exposed to the highest magnitudes. Some electronic devices (e.g. Hi-Fi, TV) are frequently in standby mode when they are deactivated, and they may also cause a weak magnetic field in such mode.

Tables 1 and 2 show the typical values of electric and magnetic fields of devices in households (source: WHO website – http://www.who.int/peh-emf/about/WhatisEMF/en/index3.html). In Table 2 the values in bold show the magnetic field at normal distance of use.

Table 1: *Typical electric field strengths, measured near electrical devices at a distance of 30 cm.*

Electrical device	Electric field strength (V/m)
Stereo receiver	180
Iron	120
Refrigerator	120
Mixer	100
Toaster	80
Hairdryer	80
Colour TV	60
Coffee machine	60
Vacuum cleaner	50
Electric oven	8
Light bulb	5

Note: Limit value for electric field strength in the ICNIRP guidelines is 5000 V/m.

Table 2: *Typical magnetic flux densities of electrical devices at various distances.*

Electrical device	**Magnetic flux density (μT) at various distances**		
	3 cm	**30 cm**	**1 m**
Hairdryer	**6–2000**	0.01–7	0.01–0.03
Shaver	**15–1500**	0.08–9	0.01–0.03
Vacuum cleaner	200–800	**2–20**	0.13–2
Fluorescent light	40–400	**0.5–2**	0.02–0.25
Microwave oven	73–200	**4–8**	0.25–0.6
Radio	16–56	**1**	< 0.01
Electric stove	1–50	**0.15–0.5**	0.01–0.04
Washing machine	0.8–50	**0.15–3**	0.01–0.15
Iron	8–30	**0.12–0.3**	0.01–0.03
Dishwasher	3.5–20	**0.6–3**	0.07–0.3
PC	0.5–30	**<0.01**	
Refrigerator	0.5–1.7	**0.01–0.25**	<0.01
Colour TV	2.5-50	0.04–2	**0.01–0.15**

Note: Limit value for magnetic flux density in the ICNIRP guidelines is 200 μT.

2.2 Electric power transmission network facilities and devices

High voltage electric power facilities (such as overhead power lines, cable lines, switching and transformer substations or all devices with rated voltage higher than 1 kV) are significant low frequency electromagnetic field sources in the environment. Slovenian legislation regarding electromagnetic fields sets the limits and control guidelines for integrating these sources in environment (this is more specifically determined by the Decree on Electromagnetic Radiation in the Natural and Living Environment, Official Gazette of the Republic of Slovenia no. 70/1996), which is one of the strictest decrees in the world. For infrastructural facilities, professionals verify whether the values of the electromagnetic fields in the living environment comply with the decree.

While electric fields around electric power facilities are practically constant with regard to time, since the voltage conditions practically do not vary in time, magnetic fields vary in time, because electric currents can vary significantly in time. Therefore, the highest evaluated magnetic field value at a specific location does not show the current exposure or time-averaged exposure, but only the highest possible exposure rate.

The eventual field limit value exceeding is verified by calculations before siting of the EMF source in environment, while measurements and calculations are used after the siting in environment. General calculations of fields were implemented in initial field analyses, and more detailed calculations have been developed with the progress of information tools. Modern approach is used in general to consider every electric power facility (overhead lines, cable lines, switching transformer station) individually with detailed field calculations that embrace 3D modelling by including detailed spatial data.

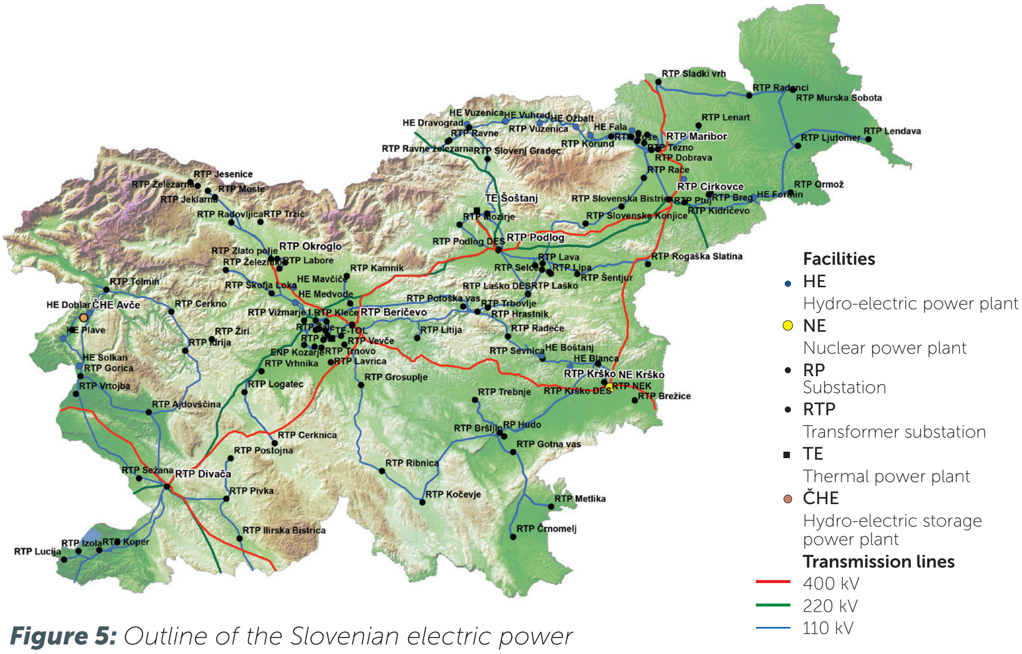


Figure 5: *Outline of the Slovenian electric power transmission system.*

2.2.1 Overhead electric power lines

Electric power is transmitted across the country through overhead power lines operating at various voltage levels. Among electric power facilities, overhead power lines are mostly distributed across the country. They are the source of electric and magnetic fields. Field values decrease from conductors with the inverse square of distance; the highest values that people can be exposed on the ground, are directly below the overhead power line and rapidly decrease moving away from the line on both sides.

While the highest magnetic field magnitudes can be encountered near electrical devices at home, the highest electric field magnitudes in the environment can be found below the overhead power lines of the highest voltage level (400 kV), i.e. roughly up to 10000 V/m. Below overhead power lines with 220 kV rated voltage, the electric field can attain a maximum of 5000 V/m, below overhead power lines with 110 kV rated voltage, it may amount to 3500 V/m. Magnetic field under 400 kV overhead power lines reaches max. to 50 μT at highest line load, under 220 kV overhead power lines it reaches max. 25 μT, and under 110 kV overhead power lines it reaches max.15 μT respectively.

The following parameters impact the distribution of the electric and magnetic fields around overhead lines conductors:
- the geometry of conductors in the 3D space,
- phase arrangement of conductors,
- electric voltage and electric current.

Figures 6 and 7 present the distribution of electric and magnetic field magnitudes perpendicular to the overhead power line axis at the height of 1 m above the ground for three selected types of pillars of different rated voltage levels at the minimum permissible height of conductors above ground.

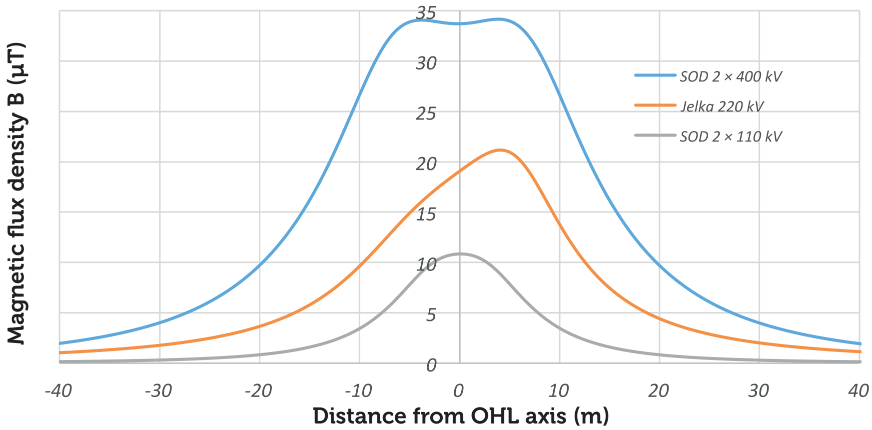


Figure 6: *Magnetic field 1 m above the ground on a perpendicular plane to the axis of the overhead power line (at the min. permissible height of conductors above ground).*

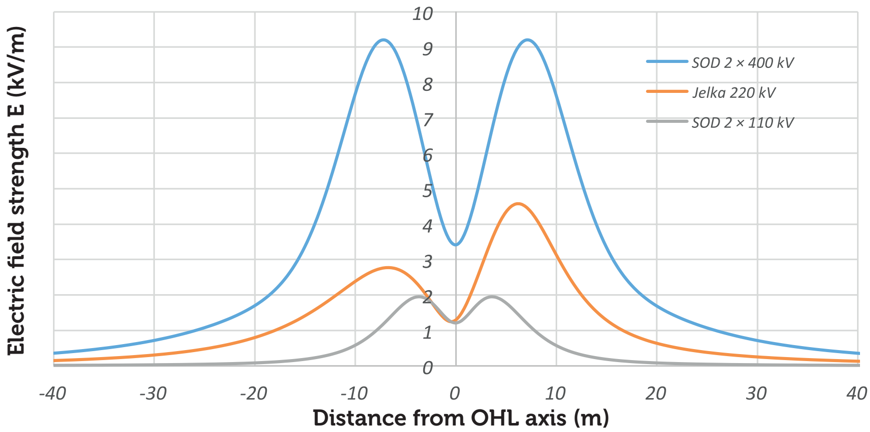
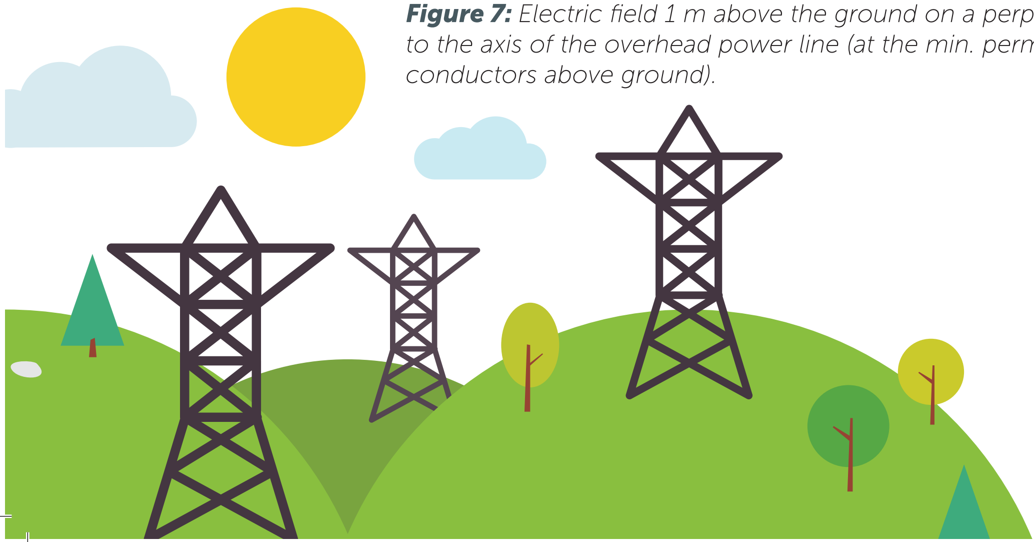


Figure 7: *Electric field 1 m above the ground on a perpendicular plane to the axis of the overhead power line (at the min. permissible height of conductors above ground).*



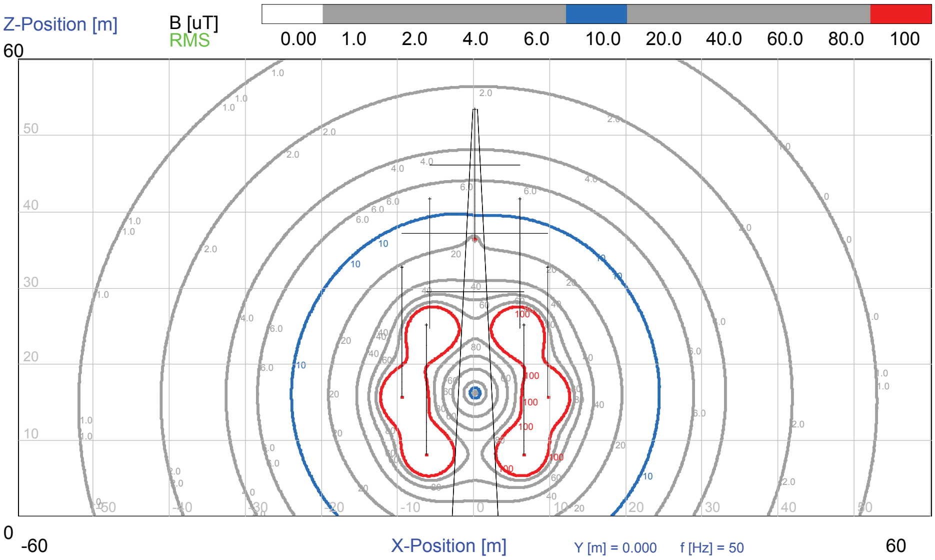


Figure 8: *Presentation of a general calculation of magnetic field on a perpendicular plane to the axis along the double system overhead line axis (SOD).*

Worst case evaluations of the field and evaluated distances to limit values, acquired on the basis of general field calculations – designated approximative corridors – are only evaluations for the maximal situations that can emerge on the route of electric power lines. In general, every facility is analysed with detailed calculations of fields that include the modelling of the overhead power line in the 3D environment. Within the approximative corridor the use of space as an area of increased level of protection is permissible only if positive conclusions of micro location field analyses with detailed 3D data of the geometry of line conductors at specific locations are obtained. In such a case the actual situation and contours of the electromagnetic field at this micro location are established.

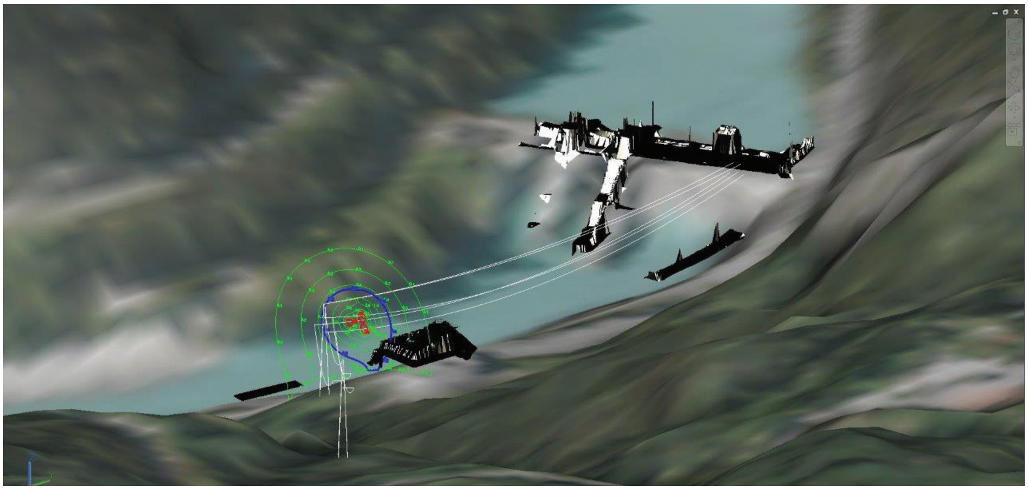


Figure 9: *Presentation of a detailed micro location calculation of the electric field on a perpendicular plane to the overhead line axis at the selected object.*

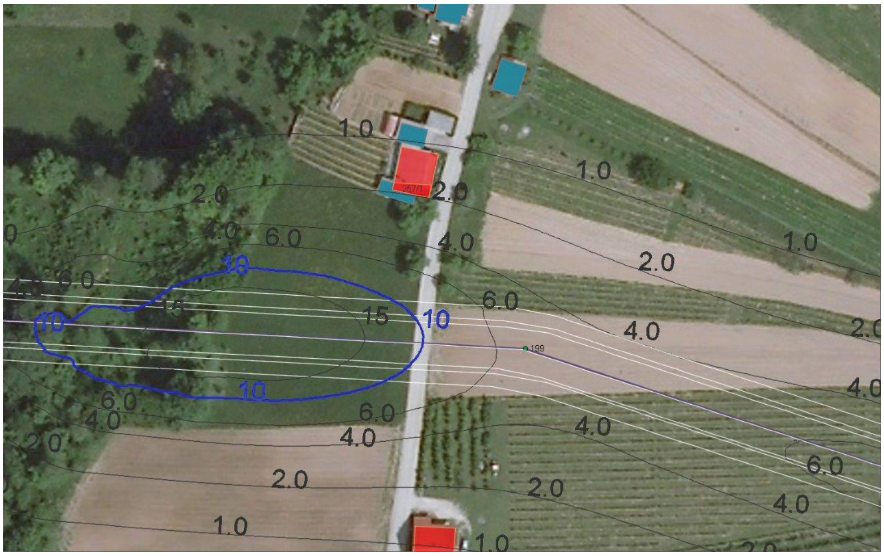


Figure 10: *Presentation of a detailed micro location calculation of magnetic field B [μT] 1 m above the ground at the selected object.*

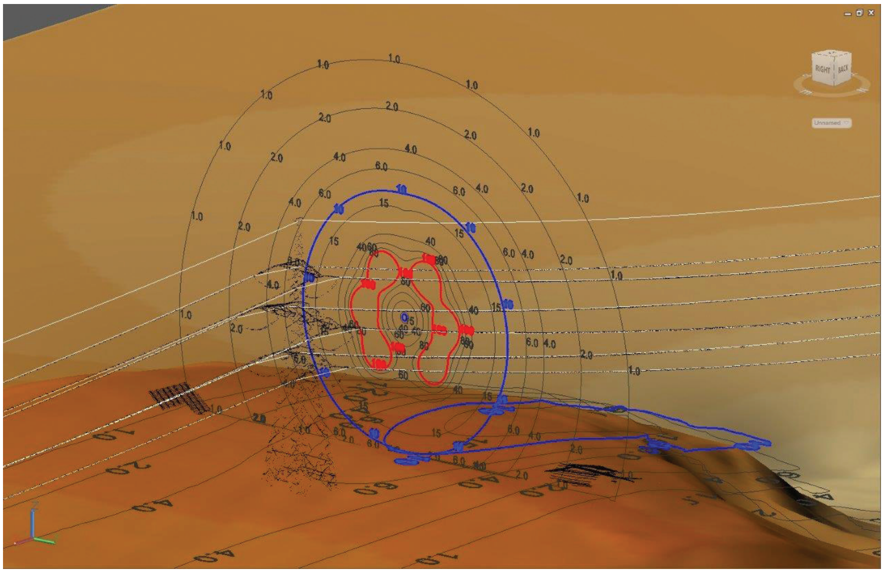


Figure 11: *Presentation of a detailed micro location calculation of the magnetic field B [μT] 1 m above ground and on a perpendicular plane to the overhead line axis at the selected object.*

2.2.2 Underground cables

High voltage underground cables produce only magnetic fields. In case of underground cables single insulated phase conductors can be closer to each other, and as a result of that the field is lessened. If they are not buried too deep, we can get closer to them, meaning that we can be exposed to higher magnetic field magnitudes. In general, magnetic field magnitudes at the ground level near underground cable lines are fading much more intensively with the distance from the line axis than in case of overhead lines; however, they can be higher near at the cable line axis than near the overhead power line (Figure 12).

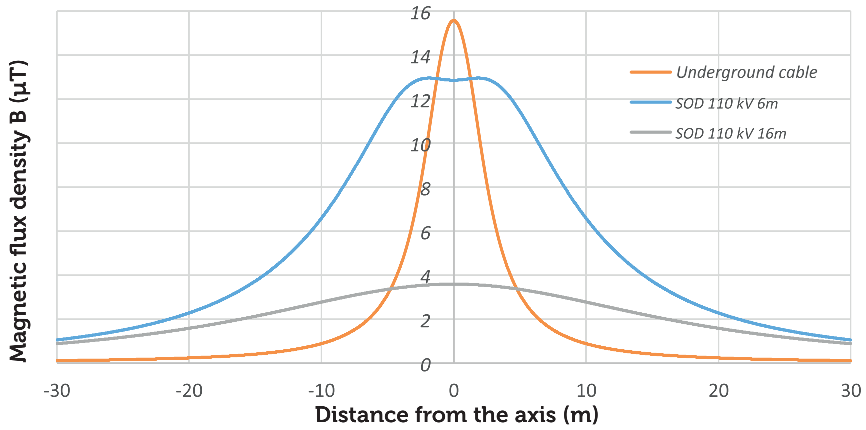


Figure 12: *Magnetic field at 1 metre above ground in cross section to the cable axis; comparison for the 110 kV cables where they are set on the plane with 25 cm distance (orange), for the overhead power line SOD where the lower conductor is set at the height of 6 m (blue) and 16 m (grey).*

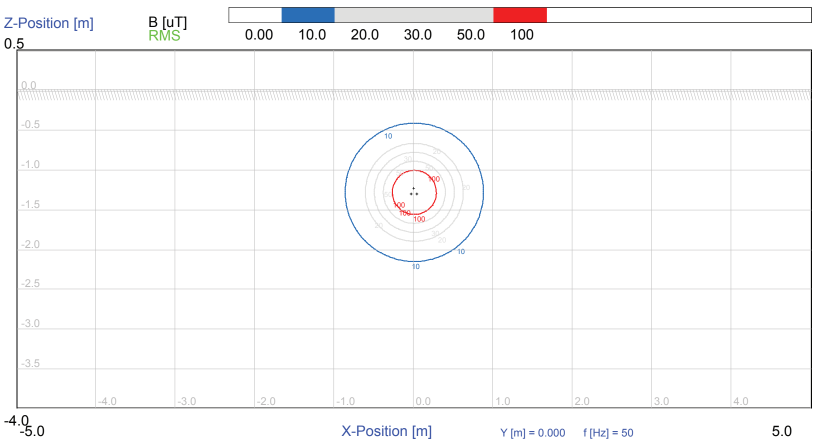


Figure 13: *Presentation of the general magnetic field calculation on a perpendicular plane to the 110 kV cable axis for the type geometry of laying the cables in trefoil formation closely together.*

Also for underground cable lines the detailed calculation can be made with 3D modelling and including detailed spatial data (Figures 14 and 15).

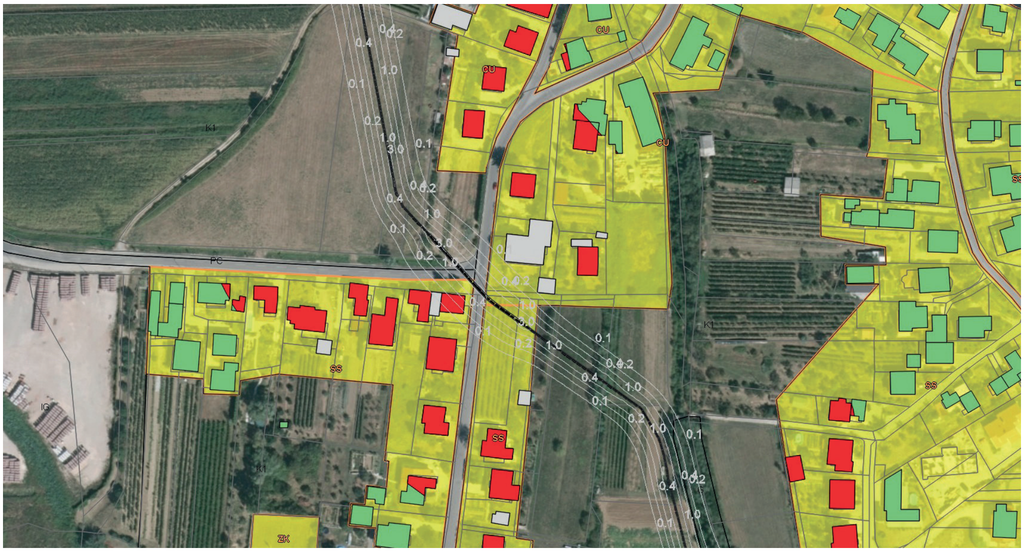


Figure 14: *Presentation of a detailed micro location calculation of magnetic field B [μT] 1 m above the ground at the selected object.*

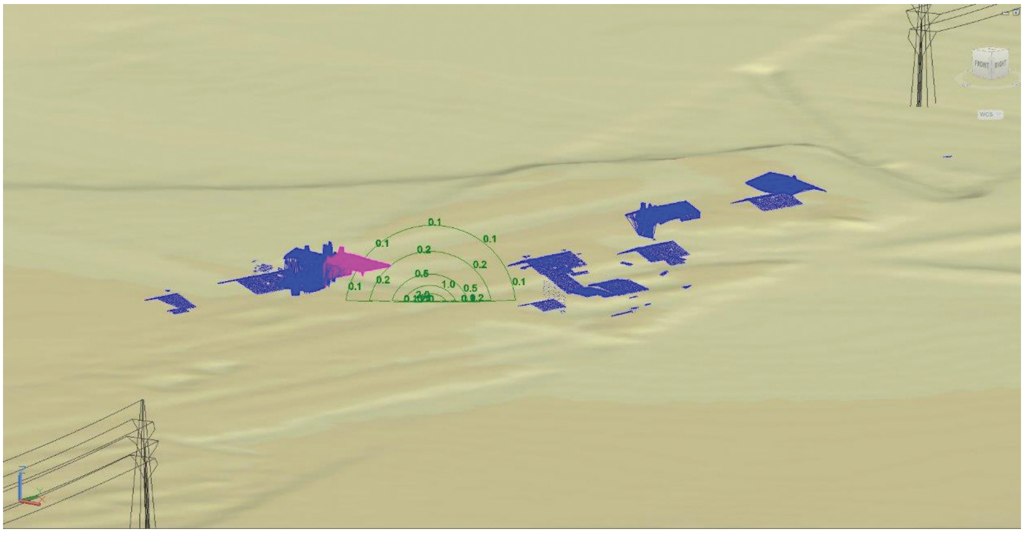


Figure 15: *Presentation of a detailed micro location calculation of the magnetic field B [μT] on a perpendicular plane to the underground cable axis at the selected object.*

2.2.3 Substations

A substation is a functional part of the network placed in a carefully selected area and containing usually mostly switching devices and transformers as well as connections to transmission lines.

In almost all cases, the highest electric and magnetic field values outside the fenced substation area are produced by overhead power lines and cables, but not by the equipment within the substation itself. Field magnitudes caused by the substation or its elements usually decrease significantly within the fenced area or a couple of metres on the external side of the fence.

A metal fence surrounding the substation ensures that the electric field magnitudes due to the substation electric equipment are usually small outside the substation fence. The equipment at the substation is also the source of a magnetic field, but its magnitude decreases quite quickly. The highest values of the magnetic field outside the substations almost always arise from the connected overhead power lines and underground lines.

The modern approach includes 3D substation modelling by considering detailed spatial data.

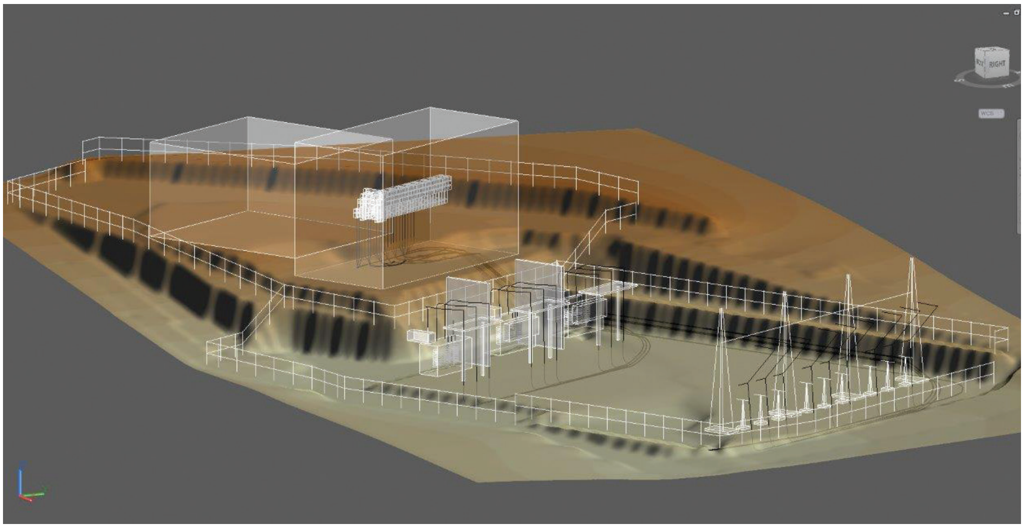


Figure 16: *3D model of a substation.*

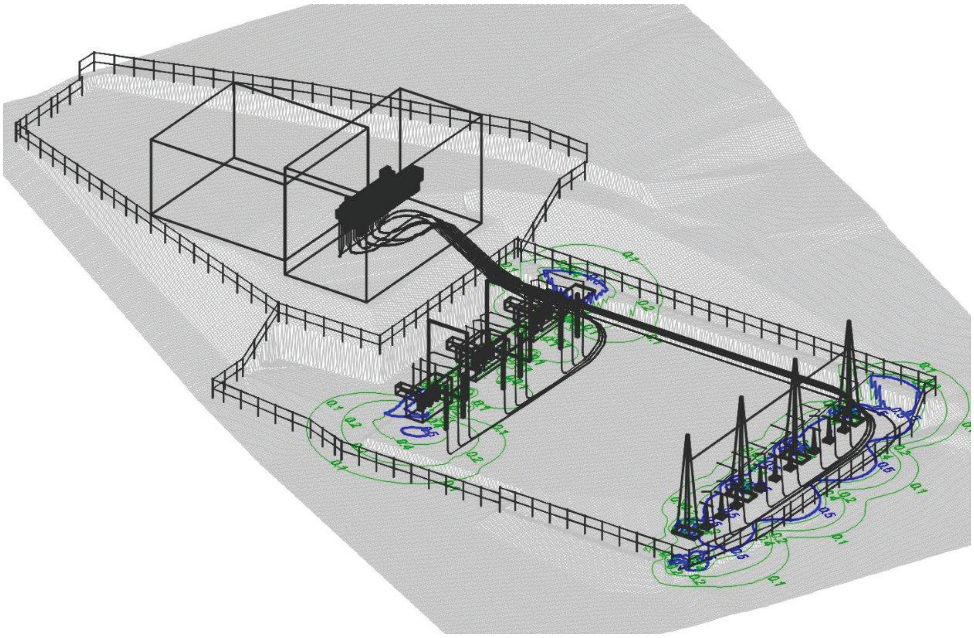


Figure 17: *Presentation of a detailed micro location calculation of magnetic field B [μT] 1 m above the ground at the substation.*

Let's repeat

- Slovenian legislation sets the limits and control procedures for handling of significant sources of low frequency electromagnetic fields in the environment (high voltage electric power facilities such as overhead power lines, cables, substations or all devices with more than 1 kV rated voltage).
- Electric fields near electric power facilities are practically constant over time, because the voltage conditions practically do not vary in time. Magnetic fields, however, may vary in time, because electric currents can vary significantly in time.
- Modern approaches are used in general to consider every electric power facility (overhead lines, substations) individually with detailed calculations of fields that include 3D modelling by including detailed spatial data.

3 Limit values for EMF exposure

The purpose of limit values is to protect people (general population and occupationally exposed) against the harmful effects of EMF.

3.1 ICNIRP Guidelines

ICNIRP is the acronym of International Commission on Non-Ionizing Radiation Protection and is in this field considered as the authority on the international scale. Its tasks include the formation of a scientific database about the health effects of EMF, the separation between scientifically credible proven and non-proven health effects of EMF and the drafting and publishing of recommendations for limiting the exposure of people.

The newest guidelines of ICNIRP, published in 2010 (Guidelines for limiting exposure to time-varying electric, magnetic and electromagnetic field (1 Hz to 100 kHz), 2010) are based on the current professional know-how in protecting people against the harmful effects of electromagnetic fields. The limit values provided for the general population for power frequency fields, are **E = 5 kV/m and B = 200 μT.**

3.2 Council of the European Union recommendation

In EU, a recommendation was adopted in 1999 for the protection of the general population against electromagnetic fields. This document recommends to the governments of the EU member countries regarding setting the measures for limiting the exposure of people to electromagnetic fields to consider the basic restrictions and reference limit values (the reference limit values for 50 Hz frequency are **5 kV/m and 100 μT).**

3.3 Slovenian regulation

The Decree on Electromagnetic Radiation in the Natural and Living Environment has been in force in Slovenia since 1996. It has determined the electric power facilities with rated voltage above 1 kV as the sources of electromagnetic fields and has divided them into existing and new or reconstructed sources of EMF regarding the date of the acquired building permit. It has divided the environment in two categories: the category I area and category II area of protection against EMF. The category I areas have an increased level of protection against EMF, the category II areas comprise the remaining areas. The limit values for electric and magnetic fields of network frequency are:

A) **E = 10 kV/m in B = 100 μT** - for the existing sources of EMF (for those which had acquired the building permit before 24 December 1996) in category I and category II areas and for new and reconstructed sources of EMF in the areas with a mild level of protection against EMF (in category II areas),

B) **E = 0,5 kV/m in B = 10 μT** - for new and reconstructed sources of EMF in areas with an increased level of protection against EMF (in category I areas).

Slovenian legislation also determines limit values and the methodology as well as the locations for verifying the values of the electromagnetic field. The decree stipulates that an assessment with regard to electromagnetic fields is made for each new or reconstructed source of EMF before its integration in the environment, after the construction the first measurements of fields and for sources with rated voltage of 110 kV and higher, every five years operational monitoring is implemented.

Let's repeat

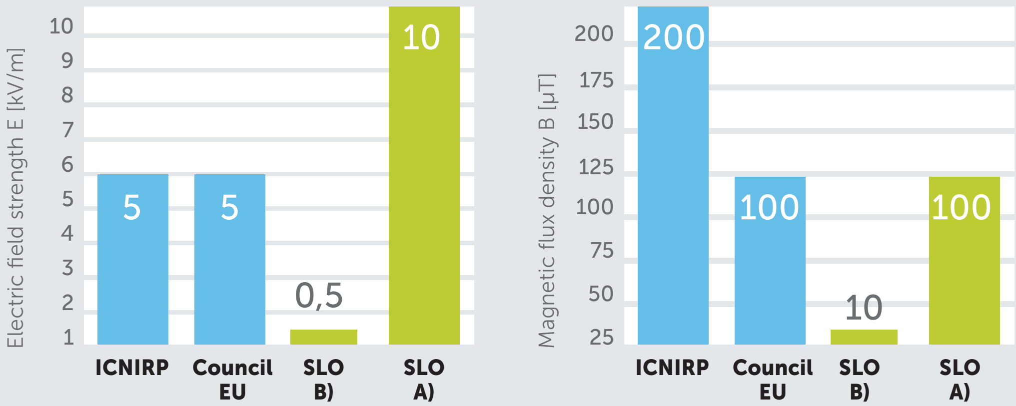


Figure 18: *Comparison of limit values of electric and magnetic fields.*

4 Effects of electric and magnetic fields on people

There is no doubt that electric or magnetic fields measurably or with noticeable consequences impact organisms, if their magnitudes are high enough; these acute effects have been scientifically proven. However, the field magnitudes that usually occur in our natural and living environment are too low to cause such acute effects.

If a person is in an electric field, the electric charge is distributed on the surface of the body, and in the body there are electric currents and weak electric field. The magnetic field induces electric currents or weak electric field in the body. These electric currents are very low when exposed to fields that we usually record in our natural and living environment. There has been no consensus that fields would have adverse effects, except with regard to fields that are strong enough to induce flux densities above the neural and muscular stimulation limit. The mentioned effects of stimulating the nervous and muscular system emerge at significantly higher values of fields than are normally recorded in our natural and living environment.

In the international ICNIRP guidelines the limit values for electric and magnetic fields of 50 (60) Hz are based on acute effects of currents that are induced in the body due to electric and magnetic fields, and they also include additional safety factors.

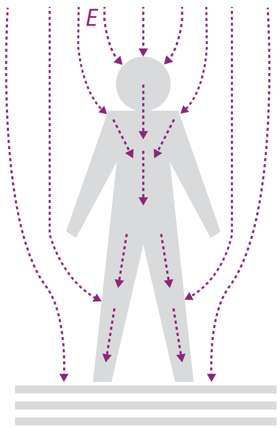


Figure 19:
Person in an electric field.

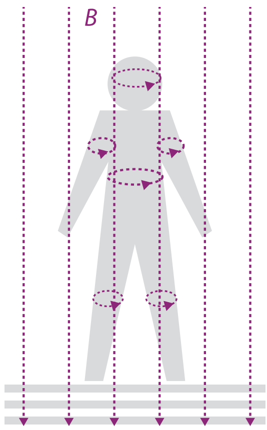


Figure 20:
Person in a magnetic field.

Acute effects are therefore scientifically proven; however, there is a certain level of uncertainty with regard to potential effects of long-term exposure to field magnitudes that are lower than the limits set on the basis of acute effects.

The World Health Organisation (WHO) monitors electromagnetic radiation as a factor that can have an effect on the health of people. It publishes information about general facts about electromagnetic fields and their impacts on health, about standards and legislation models etc. on its website http://www.who.int/ peh-emf/en/.

In its backgrounder Electromagnetic Fields and Public Health (June 2007), the WHO has stated that in October 2005, WHO convened a Task Group of scientific experts to assess any risks to health that might exist from exposure to ELF electric and magnetic fields in the frequency range > 0 to 100 000 Hz (100 kHz). The experts reviewed evidence about numerous health effects, including cancer. They found that there have been no health issues that would refer to the electric field of extremely low frequencies at the levels to which the general population is normally exposed. With regard to the magnetic field of extremely low frequencies, experts concluded that biological effects due to acute exposure at high values (highly above 100 μT) have been proven and explained with recognised biophysical mechanisms.

With regard to potential long-term effects of exposure, most scientific research has focused on leukaemia in children.

In 2002, the International Agency for Research on Cancer (IARC) published a monograph classifying magnetic fields of extremely low frequencies as "possibly carcinogenic to humans". This classification is used to denote an agent for which there is limited evidence of carcinogenicity in humans and less than sufficient evidence for carcinogenicity in experimental animals. This classification based on the results of epidemiological studies, showing that children who were exposed to magnetic fields with average magnitude higher than 0,3 or 0,4 μT displayed a mild, but observed increased risk for leukaemia.

The IARC classification "Possibly carcinogenic to humans" is the weakest among three categories (Group 1 "Carcinogenic to humans", Group 2A "Probably carcinogenic to humans" and Group 2B "Possibly carcinogenic to humans"), that are used to classify potential carcinogenic substances on the basis of published scientific evidence (Group 2B includes coffee and radio frequency electromagnetic field). The connection between the exposure to magnetic fields and childhood leukaemia due to non-consistencies in establishing the exposure and lack of support in other necessary research (especially the probable explanation of basic mechanisms) does not suffice the criteria for unequivocally confirming the causal relationship.

The SCENIHR is the Scientific Committee on Emerging and Newly Identified Health Risks working in the framework of the European Union. In the summary of the Opinion on Potential health effects of exposure to electromagnetic fields, the SCENIHR indicated:

"The new epidemiological studies are consistent with earlier findings of an increased risk of childhood leukaemia with long-term average exposure to magnetic fields above 0.3 to 0.4 μT. However, as stated in the previous opinions, no mechanisms have been identified that could explain these findings. The lack of experimental support and shortcomings identified for the epidemiological studies prevent a causal interpretation."

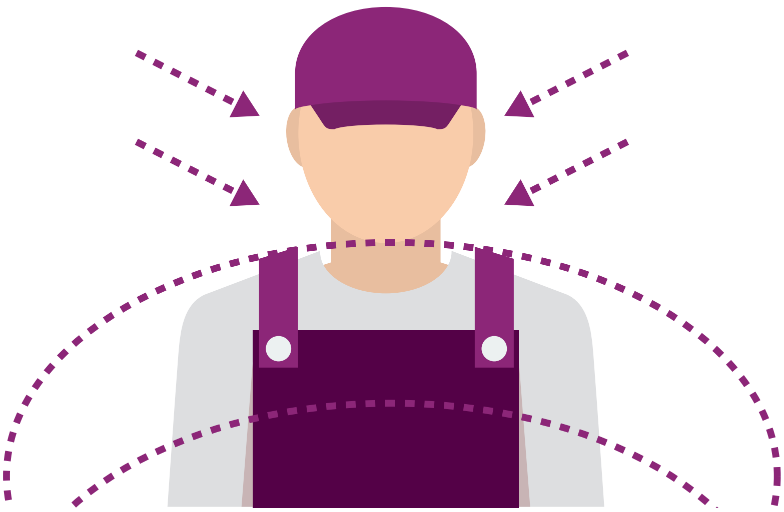
Considering the possible causal connection with the exposure to low frequency magnetic field, other potential adverse effects on health have been researched (other childhood cancers, cancers in adults, depression, suicide, cardiovascular disorders, reproductive dysfunction, developmental disorders, immunological modifications, neurobehavioural effects and neurodegenerative disease). The WHO Task Group concluded that scientific evidence supporting an association between ELF magnetic field exposure and all of these health effects is much weaker than for childhood leukaemia. In some instances (i.e. for cardiovascular disease or breast cancer) the evidence suggests that these fields do not cause them.

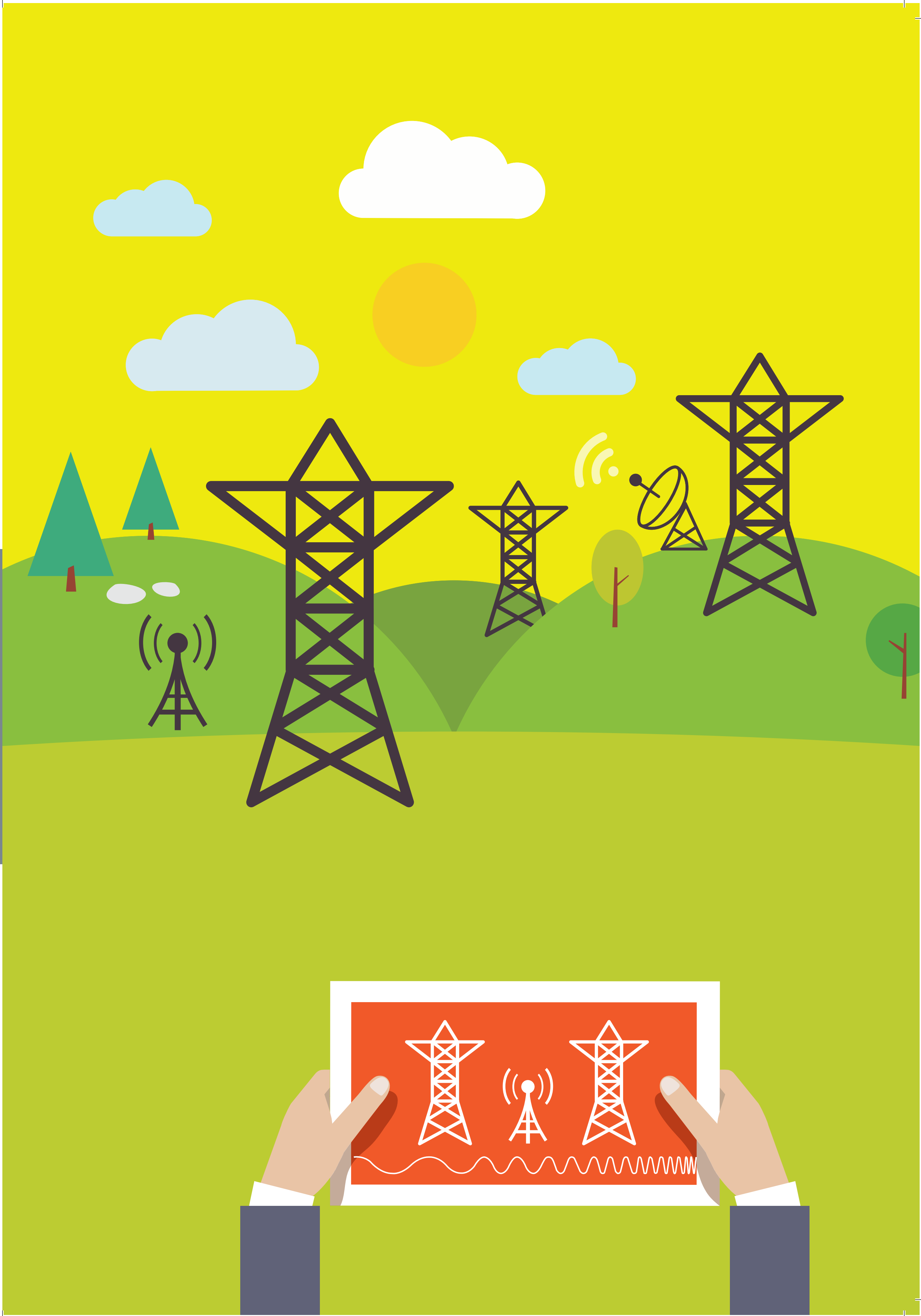
The current international ICNIRP guidelines, presenting the basic protection standard that bases on scientific findings, consider that the scientific evidence with regard to the potential effects on health from long-term exposure to low magnitudes of electromagnetic radiation is insufficient to eligibly lower the limit values of exposure.

The Slovenian legislation determines very strict limit values in the areas of increased EMF protection level for new facilities, which are much stricter than the limit values in the ICNIRP guidelines.

Let's repeat

- Electric and magnetic fields have effects on people without a doubt – but only at high magnitudes, i.e. higher than the magnitudes that are usually present in the residential and natural environment. These acute effects have been scientifically proven.
- There is a certain level of uncertainty with regard to potential effects of long-term exposure to field magnitudes that are lower than the limits set on the basis of acute effects.
- The World Health Organisation states that the evidence for connection between exposure to magnetic fields and childhood leukaemia is not strong enough to be considered causal.





Literature

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