ELF ELECTRIC AND MAGNETIC FIELDS MEASUREMENTS IN GREECE

E. Karabetsos, G. Filippopoulos, D. Koutounidis CH. Govari, N. Skamnakis
Non ionizing radiation office, Greek atomic energy commission, P. O. BOX 60092, 15310 Agia Paraskevi, Greece

Abstract
The Greek Atomic Energy Commission (EEAE) is the competent national authority for the protection of the general public and the environment from artificially produced non-ionizing radiation. To this end, EEAE carries out measurements in the vicinity of all kinds of sources emitting ELF electric and magnetic fields (e.g. power lines and substations), in order to monitor whether the general public exposure limits are being adhered to. The limit values for the ELF fields in Greece are set exactly the same as those in ICNIRP's guidelines. EEAE has conducted many measurements regarding the levels of ELF electric and magnetic fields in Greece around the elements of the electric power grid where the main interest of the public is focused. Theoretical estimations and typical values based on actual measurements of the fields in the vicinity of all the power lines used in Greece are presented. Measurement results in the vicinity of substations are also presented. In general, the levels of the magnetic field in the vicinity of the power grid elements are well below the established limits; whereas the levels of the electric field may reach values comparable to the safety limits very close to extremely high voltage lines. However, there is no case where the measured values of electric or magnetic fields were higher than the safety limits.

Introduction
Extremely low frequency or ELF electric and magnetic fields are omnipresent in modern societies. The possibility that long-term exposure to these fields might cause adverse health effects is a source for concern, especially for those people residing or working nearby high voltage lines or substations. Competent international scientific committees are watching the scientific developments in order to reach general conclusions about the health effects of these fields, [1].

In 2002, Greece put into force a legislative act, [2], implementing the recommendation, [3], of the Council of the European Union, adopting ICNIRP's limit values, [4], for the protection of the general public. The competent national authority for the protection of the general public and the environment from artificially produced non-ionizing radiation in Greece is the Greek Atomic Energy Commission (EEAE). To this end, the EEAE carries out measurements in the vicinity of all kinds of facilities emitting ELF electric and magnetic fields (e.g. power lines, high voltage substations) in order to monitor whether the general public exposure limits are being adhered to. The EEAE has been accredited in accordance with the requirements of the EN ISO/IEC 17025 standard for performing this kind of measurements. Figure 1 shows the number of annual audits conducted by the Non Ionizing Radiation Office of EEAE in the vicinity of ELF sources. There is an incremental tendency in these measurements reflecting the increasing interest for them.

Fig. 1. Annual audits conducted by the Non Ionizing Radiation office of EEAE concerning ELF sources.
In the next paragraphs the main sources of ELF electric and magnetic field exposure of the general public are presented. Domestic sources as the electrical appliances, internal wiring and currents on large grounded metallic objects as water pipes, drains and rails are presented. Also, the exposure resulted from the electric power transmission and distribution system is examined. Special emphasis is given to the situation in Greece and its particularities in relation to other parts of the world. That is because the levels of the electric and magnetic fields are to an important extent depending on the practices applied at electrical installations and on the electric power grid construction and operation, which might be quite different from country to country, [5].

**Domestic Sources**

In domestic environments the most common sources of ELF fields are the electric appliances, the internal wiring as well as the currents in large grounded objects as water pipes, drains and rails. These sources mainly create magnetic fields in their vicinity, because the created electric field is small due to the low voltage and is further attenuated by closures, walls etc.

The magnetic fields produced by appliances are rapidly attenuated with increasing distance from them and are noteworthy at distances much lower than 1 meter. The field at the surface of the appliance might be very strong, reaching values of hundreds µT. However, in most practical cases the human exposure takes place at much greater distances. Exceptions to this are devices that require their operator to be in close vicinity as electric shavers and hair driers. However, these devices are usually used for short time-periods each day and so the exposure of their operators is limited. Furthermore, exposure from these devices is locally focused in a small area of the body and the coupling of the field with the human body is weak. Taking into account these special exposure situations it is rather impossible that exposure from these sources might be capable to stimulate the neural or muscle cells.

The internal electrical wiring usually does not create important magnetic field levels in its vicinity. The involved practices applied at the construction of these installations are described in the electrical safety codes for the avoidance of the electrocution and other dangers. According to the safety code in Greece, [6], but also in many other parts of the world, the currents at the internal wirings create magnetic fields that at a great extent cancel each other. However, in the rare cases of installations not complying with the terms of the safety code, it is possible to find unusually strong magnetic fields, due to faulty connections or leakage currents. The existence of strong magnetic fields from the internal wiring might be an indication of an installation not complying with electrical safety codes and even hiding risks for electrocution or other dangers (as initiation of a fire).

It is noteworthy that in Greece the main supply is 50Hz and 220V ac voltage (as in the rest of Europe). That means that the currents used in electric appliances and the magnetic fields associated with them are roughly half of those that are used in other parts of the world (as the North America) where 110V are used. Furthermore the 50Hz magnetic fields in Europe induce 20% less internal fields and currents in the body of an exposed individual in relation to the 60Hz used in North America.

Another important source of domestic ELF magnetic fields might be the existence of ground currents at large grounded objects as water pipes, drains and rails. These currents create elevated levels of background magnetic fields, i.e. fields that decay relatively slowly with the distance from their source. These currents are actually a portion of the returning currents normally located at the neutral conductor. However, the multiple ground connections of the neutral conductor allow alternative paths for the flow of the returning currents back to the power grid through large grounded metallic objects as water pipes, figure 2. Ground currents typically flow if there is a fault on the power system or they can be a normal condition, if there are many connections of the neutral conductor to the ground. However, the use of non-conductive parts at the water supply system significantly reduces the levels of the return currents.
Electric power distribution

The electric power distribution network is consisted of the low and medium voltage network used for the delivery of the electric power as well as the medium to low voltage substations. In Greece the low voltage is at the nominal level of 220/380V. The medium voltage is at various nominal levels but the last years it is being standardized to 20kV.

The low voltage network is the final piece of the electric network used for the delivery of the electric power at home level. This network consists of overhead and underground lines. These lines create mainly magnetic fields in their vicinity. The created magnetic fields may reach values up to a few µT close to the conductors and attenuate at much lower levels a few meters away from the lines. However, the low voltage loads are usually not well balanced on the three phases of the system and that causes the appearance of currents on the line neutral conductor. A portion of this current might flow on large grounded metallic objects in the vicinity of the line but in special circumstances also far from it, with the results described in the previous paragraph. That also means that there is a net current on the line producing magnetic fields that decay relatively slow with the distance from it.

The medium voltage network is used for the power supply of the substations feeding the low voltage network as well as for the immediate supply of large consumers. The voltage in this network is many times higher than that in low voltage network and so the currents are many times lower for the same amount of transferred power. Table 1 includes typical EMF values found in the vicinity of medium voltage lines in Greece.

<table>
<thead>
<tr>
<th>Arrangement</th>
<th>Magnetic field (µT)</th>
<th>Electric field (V/ m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>400 kV lines</td>
<td>Worst-case scenario</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>Typical (underneath the conductors)</td>
<td>1 – 4</td>
</tr>
<tr>
<td></td>
<td>Typical (25m aside from line)</td>
<td>0.5 – 2</td>
</tr>
<tr>
<td>150 kV lines with lattice towers</td>
<td>Worst case scenario</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>Typical (underneath the conductors)</td>
<td>0.5 – 2</td>
</tr>
<tr>
<td></td>
<td>Typical (25m aside from line)</td>
<td>0.1 – 0.2</td>
</tr>
<tr>
<td>150 kV compact lines on poles</td>
<td>Worst case scenario</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Typical (underneath the conductors)</td>
<td>0.3 – 1.5</td>
</tr>
<tr>
<td></td>
<td>Typical (25m aside from line)</td>
<td>0.05 – 0.2</td>
</tr>
<tr>
<td>150 kV underground cables</td>
<td>Worst case scenario</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>Typical (above the cable)</td>
<td>3 – 6</td>
</tr>
<tr>
<td></td>
<td>Typical (25m aside from cable)</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>20 kV overhead lines (medium voltage network)</td>
<td>Worst case scenario</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Typical (underneath the conductors)</td>
<td>0.2 – 0.5</td>
</tr>
<tr>
<td></td>
<td>Typical (25m aside from line)</td>
<td>0.01 – 0.05</td>
</tr>
</tbody>
</table>

Table 1. Electric and magnetic field levels at the vicinity of the power lines used in Greece. The values refer at a distance of 2m above ground level in the vicinity of overhead lines and at ground surface in the vicinity of underground cables.
It is noteworthy that the medium voltage lines do not suffer from the unbalances mentioned for low voltage lines, because the medium voltage loads are usually well balanced and the medium to low voltage substations act as barriers not allowing the low voltage unbalance to pass on the medium voltage side.

The medium to low voltage substations are usually sources of public concern. The attention is mistakenly focused on the transformer, which is used for power transmission from one voltage level to another. However, the transformer itself is not producing any significant levels of electric and magnetic fields in its vicinity. It is the medium and low voltage conductors connected to the transformer that create the electric and magnetic fields. Typically, the medium voltage equipment is the dominant source of the electric fields and the low voltage one is the dominant source for the magnetic fields close to a substation. The electric and magnetic fields produced by these substations does not extent further than a few meters from it. However, the current on the low voltage lines, which are fed by the substation, is higher close to the substation than far from it, as the electric power is dispatched to the various consumers along the line’s way.

**Electric power transmission**

High and extremely high voltage lines are used to carry vast amounts of electric power. In Greece the main centers for electric power generation are located at the north part of the country; whereas the main consumption is occurring at the south part nearby Athens metropolitan area. Three double circuit 400kV (extremely high voltage) power lines are used to carry the electric power from the north to the south. Also, 400kV power lines are used for the interconnections with the neighbour countries at the north. The rest of the transmission is mainly accomplished with 150kV (high voltage) single or double circuit power lines.

**Figure 3** shows typical levels of the electric and magnetic fields in the vicinity of the 150kV overhead power lines used in Greece. The magnetic field calculations refer to 50MVA apparent transferred power, which is considered typical for this level of voltage. The capacity for power transmission of these lines reaches 202MVA per three-phase circuit. In the 3rd row of this figure the fields in the vicinity of compact...
single circuit line are shown. This line creates the least field levels in its vicinity as it was also shown in [7].

Similarly, figure 4 shows typical levels of the electric and magnetic fields in the vicinity of 400kV power lines used in Greece. For these lines the magnetic field calculations refer to a typical level of apparent transferred power of 350MVA (typical capacity is 1400MVA per three-phase circuit). In the 2nd and 3rd row of this figure the fields in the vicinity of a double circuit line with different phase arrangements are shown. The double circuit 400kV power lines in Greece used to be constructed with the symmetrical phase arrangement on the two circuits (2nd row). However, for the barrel type double circuit lines used in Greece, this phase arrangement is not the optimum for the reduction of the produced electric and magnetic fields (actually for the parallel operation of the two circuits this phase arrangement is the worst one) and this led to elevated levels of electric and magnetic fields. The new 400kV double circuit lines are now constructed with opposite phase sequence on the two circuits, which is the optimum phase arrangement (3rd row) for this type of lines and leads to reduced electric and magnetic fields, [7]. Also, the phase sequence on the existing power lines of this kind were switched to the optimum one causing significant reduction of the produced fields, [8].

In Greece there are about 10000km of overhead high voltage power lines (400kV and 150kV) as well as 200km of underground high voltage power lines (150kV). The later are used for transferring high voltage power in the dense populated urban areas. Underground cables do not produce any electric field above the ground. Comparing the magnetic fields produced by an overhead and an underground high voltage line, carrying the same power, the underground cable produces a higher magnetic field value in a narrow area right above it (figure 5).

Table 2 shows worst-case values (based on theoretical estimations) and typical values (based on actual measurements) of electric and magnetic fields in the vicinity of the power lines used in Greece. The levels of the magnetic field are, as a rule, much lower than ICNIRP’s reference level for general public exposure to 50Hz magnetic fields (100 µT), [4]. The levels of the electric field can reach values close to 5kV/m (ICNIRP’s reference level for general public exposure to 50Hz electric fields) under 400kV lines.
and under worst-case considerations. However, in no case the measured values for the electric field were higher than ICNIRP’s reference level.

**High Voltage Substations**

Regarding the electric and magnetic fields produced in the vicinity of high voltage substations the measurements conducted by EEAE have shown that the equipment installed into the substation does not produce any significant values of electric and magnetic fields outside the substation. It is the power lines connected to it, that produce the levels of electric and magnetic fields measured in the vicinity of the substations. Figure 6 shows a satellite photo of Agios Stefanos 400kV substation of the Greek power transmission system. EEAE was called upon to examine the levels of the produced fields outside this substation and performed measurements around the perimeter of it. The routes of the power lines connected to the substation as well as the measurement points are indicated in figure 6. These measurements verified that far from the power lines there are insignificant levels of fields, whereas close to the power lines the typical electric and magnetic field levels in the vicinity of the corresponding lines are found.

![Fig. 5. Magnetic field in the vicinity of a 150kV underground cable carrying 50MVA. The considered cable is buried at 1.5m depth and the distance between the neighbor pole centers is 25cm.](image)

![Fig. 6. Satellite photo of Agios Stefanos 400kV substation (Greece) where the routes of 150kV and the 400kV power lines connected to it and the locations where EEAE have conducted measurements outside its perimeter are indicated.](image)
Conclusion
The main sources of ELF magnetic field exposure of the general public in domestic environments are the
electrical appliances, the internal wiring and the return currents on large grounded metallic objects as
water pipes, drains and rails. The electrical appliances produce fast decreasing fields with distance that
typically are considered important only for those devises where the operator must be in the close vicinity
of them. The internal wiring normally does not produce any significant levels of magnetic fields, unless
there is a faulty connection or a leakage current. The return currents on large grounded metallic objects
as water pipes, drains and rails cause elevated levels of background magnetic fields.

Unbalanced loads at low voltage lines might cause net currents on them creating magnetic fields that
decay relatively slowly with the distance. The medium voltage network does not suffer from these
unbalances. The medium to low voltage transformer does not actually produce any fields in its
environment. It is the lines connected to it that produce the electric and magnetic fields in its vicinity.

The electric and magnetic fields in the vicinity of high and extremely high voltage power lines depend on
the type of line, its load and the distance from it. In Greece the application of the optimum phase
arrangement at double circuit 400kV power lines caused a significant reduction of EMF levels around
them. Furthermore, the use of compact lines also reduces the produced fields in relation to lines with
normal dimensions. Underground cables create magnetic fields that decay very fast with distance from
them. However, the magnetic field might be higher than that of an overhead line in a narrow zone
above the cables.

References
1. G. Filippopoulos, E. Karabetsos, D. Koutounides, Ch. Govari: Health effects of ELF electric and
magnetic fields – WHO/IARC evaluation and other recent reviews, Second International
Workshop on Biological Effects of Electromagnetic Fields, Rhodes, Greece, October 7-11, 2002.
2. Greek legislation: Common Ministerial Decision, Protection measures for the exposure of the
general public to all low frequency electric and magnetic fields emitting devices, Act No.512/Vol.
B/25-4-2002.
3. European Union Council Recommendation of 12th July 1999 on the limitation of exposure of the
general public to electromagnetic fields (0Hz to 300 GHz) (1999/519/EC).
4. International Commission on Non Ionizing Radiation Protection (ICNIRP), Guidelines for limiting
exposure to time – varying electric, magnetic and electromagnetic fields (up to 300 GHz), Health
5. J. Swanson, W.T. Kaune: Comparison of residential power-frequency magnetic fields away from
appliances in different countries, Bioelectromagnetics, Vol 20, No 4, pp 244-254, 1999.
6. Hellenic Organization for Standardization, Requirements for electrical installations, ELOT HD 384,
2004.
7. D. Tsanakas, G. Filippopoulos, J. Voyazakis, G. Kouvarakis: Compact and optimum phase
conductor arrangement for the reduction of electric and magnetic fields, CIGRE Symposium
8. E. Mimos, D. Tsanakas, G. Filippopoulos: Measurements of electric and magnetic fields produced
by 400kV overhead power lines during the symmetrical and the optimum phase conductor
arrangement, 3rd International Workshop on Biological Effects of Electromagnetic Fields, Kos,
Greece, October 4-8, 2004.