LOW FREQUENCY FIELDS ELECTRIC DISTRIBUTION NETWORKS AND OCCUPATIONAL EXPOSURE

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REZUMAT. Efectul expunerii umane la câmpuri electromagnetice de diferite frecvențe constituie un subiect de mare actualitate. Lucrarea prezintă considerații teoretice privind caracteristicile câmpurilor de joasă frecvență produse de instalațiile electroenergetice, reglementările juridice în domeniu precum şi prevederile de bază ale standardelor tehnice care permit transpunerea lor în practică. Sunt prezentate şi comentate rezultatele unei ample campanii de măsurări în stații electrice din România ca şi o serie de considerente medicale privind expunerea umană la câmpuri electromagnetice.

Cuvinte cheie: câmp electromagnetic, expunere umană, medicina muncii

ABSTRACT. The effect of human exposure to electromagnetic fields of different frequencies is a topical subject. This paper presents theoretical considerations regarding the features of low frequency fields produced by electrical power installations, legal regulations regarding the permissible limits in this domain and also the provisions of technical standards that enable their implementation in practice. A large amount of measured data from many substations in Romania is presented and the obtained results are discussed from technical point, together with medical considerations about this subject.

Keywords: electromagnetic field, human exposure, occupational medicine

1. INTRODUCTION

In the last years concerns about the electromagnetic field effects were increased both for professionals and for the large public. Based on the researches about acute effects on human body, International Commission on Non-Ionizing Radiation Protection (ICNIRP) [1] releases periodically recommendations about the admissible limits for human beings in the different range of frequency.These recommendations serve as fundament for national or regional standards in the domain of work safety or large public protection against the effects of electromagnetic fields. In the European Union, the 40/2004/EC Directive [2] established the limit values of quantities which cannot be over passed in the workplaces, in a range of frequencies between 0 and 300 GHz. Regarding the public exposure the limits are stipulated in the 519/1999/CE Recommendation [3]. Above cited documents presents admissible values for the quantities which have direct biological effects (such as induced density current in the body or specific absorption rate) as for external/measurable quantities such as field strengths or flux densities.These documentsdo not provide the measuring procedure, the requirements for devices or apparatus which can be used to perform the measurements. To note that in these documents are specified only the limit values. To complete this task it is necessary to be followed a defined procedure, to use a measuring system with agreed performances, and also to perform the measurements in specified atmospheric conditions or, if not possible, to be applied certain corrections.

In the European Union regarding the procedure which must be followed in order to demonstrate compliance of a workplace with the exposure limit values and action values stated in the Directive 2004/40/EC, first of all must be follow the provisions of European Standard EN 50499/2010 [4]. In the list of normative references of EN 50499 it is cited among others the basic standard EN 50413/2008 [5] also dedicated of measurement and calculation procedures for human exposure in the frequency range covered by the Directive (0 ... 300 GHz). It must be emphasized that EN 50499/2010 stipulates that the compliance with Directive 40/2004/CE can be proved either by calculations or by measurements.As a result, some locations can be excluded from exposure assessment being considered implicit compliant.The power distribution installations, with rated voltages of up to 110 kV, meet the above requirements at least in terms of electric field (only accidentally it could be exceeded admissible values for public exposure, as resulted also by the measurements performed in situ and presentedin this paper).Regarding the magnetic field it must be mentioned that the slowest decreasing of its strength (H) with distance (r) from a source is recorded in the case of a single conductor (the return conductor is located far away and has no influence on the resultant value of the field).

In the case of single conductor the effective value of the H is given by$H = I/2\pi r$, I being the effective value of the current through conductor. As result, if the current which flow in conductor is 500 A, the distance at which the field strength decreases under the admissible value for public exposure (80 A/m) is 1 m and for professional exposure (400 A/m) is 0.2 m.At such a small distance from the magnetic field source can't be find the workers or general public except in atypical circumstances and only when the source is an insulated monophasic cable, posed in air (not buried) regardless its rated voltage.

The CIGRE brochure 375/2009 [6] describes the procedures used to evaluate the human exposure near overhead lines.

2. MAIN PROPERTIES OF LOW FREQUENCIES FIELDS PRODUCED BY ELECTRIC POWER INSTALLATIONS

Properties of low frequency electric and magnetic fields have been thoroughly studied and reported in many papers. At low frequency, the regime of electromagnetic field is quasi-stationary and the electric and magnetic fields can be considered decoupled, the variation of one of them having no influence on the level of other one. As result, each field can be calculated independently. The electric field in this regime has a unique source: the electric charges on the conductors, as a result of applied voltage. Due to this fact, the calculation of electric field is based on the methods used in electrostatics. An electric field will appear in the neighborhood of an overhead line once it was energized even if it's not loaded. As such, the electric field has a variation into a restricted range of values because the network operation code imposes the maintaining of voltage in prescribed limits.

Regarding the magnetic field, its unique source is the current flowing through conductors and its variation has large limits and follows the curve load of the consumer.Under three-phase overhead lines or under air insulated busbars, the electric and magnetic fields have elliptical polarization, meaning that the (rotating) field vector describes during a cycle of voltage or current an ellipse. In particular positions versus field sources, the ellipse could degenerate into a circle or into a right line. Relating of electric field and in usual conditions regarding the suspension height of conductor's, nearby the ground level the field is nearly homogenous and its vertical component predominate.The field strength depends on applied voltage and the geometry of line: the relative position and distances between conductors, the suspension heights, the real radius of conductors or the equivalent radius in case of bundled conductors and of course the position of measuring' point.In an air insulated substation due to the multiple sources of field (busbar systems, over or under crossings, connections of the equipment terminals) the electric field polarization in a given point can't be simple described, the field strength being the resultant of all three space components (in Cartesian coordinates).

Relating to the magnetic field produced by three-phase sources, in the vicinity of soil it is not a rule regarding the predominant component: it could be the horizontal or vertical one, depending of the relative position of the source conductors and the position of measuring point. The magnetic field strength depends on current values (and is recommended to be expressed relative to a unit of current, usually 1 kA for high voltage systems), the geometry of line and the position of observation point.Time variation of the resultant field is not sinusoidal although its components (horizontal and vertical) shows sinusoidal variations. As a result, the electric and magnetic fields, will have a significant DC component in some points from the vicinity of sources.

3. MEASURING PROCEDURES

The above cited standards describe the procedures used to evaluate human exposure regarding professionals and large public. There are some differences between the stipulated requirements, generally referring at the minimum admissible distances between the field probe and permanent obstacles or equipment. In the following will be presented and commented common stipulations of these standards, pertaining to the measurement of low frequency fields:

– the measurements must be performed in time domain and in conditions of undistorted field (in the absence of objects able to influence the local value of the field);
– the measurements must to be expressed in the

effective values of the resultant; as consequence, are recommended triaxial probes which offer directly the results using the three spatial measured (in r.m.s.) components (as example, for electric field, $E_{\text{res}} = \sqrt{E_x^2 + E_y^2 + E_z^2}$);

– the probes must have a relatively small size (the upper limits of their areas are specified - as example, the area of a magnetic field probe shall not exceed 100 cm^2);generally, the intrinsic uncertainty of a probe decreases with the increasing of probe surface, but its accuracy is increased only in uniform fields - their software is built and their calibration is performed in this conditions.

– minimum lateral distances (generally expressed in function of diagonal or diameter of the probe) must be kept versus conductive surfaces and/or with magnetic properties;

– the bandwidth of measuring system must be appropriate of frequencies content of the measured field (generally, up to 500 Hz; a narrow bandwidth could be accepted if the harmonics content could be neglected).

Regarding the measuring procedure, as been asserted in the EN 50413, “a preliminary scan may be performed to determine the distribution of the field”. The results of this scan shall be documented. After the point of maximum exposure was detected it’s necessary to perform detailed measurements in this point and to conclude which is the “exposure level”. Seeing the requirements in standards which treat the problem of human exposure, a preliminary scan must be performed at a specified height above the soil (1 m). If the field is uniform, the exposure level is even the measured value. In the case of non-uniform field it must perform measurements at 0.5 m, 1 m and 1.5 m heights and the average of the three values is the exposure level. In the proximity of equipment or above a buried cable, the procedure implies a number of three or five measurements and the exposure level is then calculated using an averaging formula. If in the case of magnetic field measuring, no special requirements regarding the influence of the operator on the field probe (because the human body hasn't magnetic properties), specific precautions must be taken regarding electric field measuring. In order to reduce the operator's influence to the measured value, the distance between him and field probe must be at least 1.5 m but the recommended one is 3 m. As consequence the electric field probe is disposed on a dielectric tripod or support and connected to the central unit of measuring system via an optical fiber cable. On the other hand, the electric field measurement is affected when relative humidity exceeds 70% and involved errors are only positive, considerations about this influence being given, as example, in EN 50499.

4. MEASURED DATA

To confirm or refute those provided in EN 50499 standard for occupational exposure and to identify the maximum exposure points, there was carried out a large measurement campaign that included air insulated and indoor substations with rated voltage of 110 kV and also MV/LV transformer substations owned by a Romanian company of power distribution. There was used measuring professional type equipment with an intrinsic uncertainty of 3% both for electric and magnetic field probes and the atmospheric conditions were adequate (fair weather, relative humidity under 60%). In the substations, measurements were performed both on access paths, with a step of 1 m (in order to identify the maximum values), and in proximity to equipment such as power transformers, actuator devices for switching equipment, relays cabins.

Unusual values were not recorded regarding the field value in the proximity of power transformers even at a distance of 1 m against their case.Despite of what one might think about their presence as magnetic field sources, transformers are constructed so as to present magnetic flux leakage as little as possible, in order to increase their efficiency. On the other hand, their metallic case acts also as shield against magnetic field. Thus, measuring performed close to 110 kV/MV transformers (having apparent power between 16 MVA and 40 MVA) reveals values of field strength between 1.5 A/m and 4.6 A/m. Generally, on the access path and in vicinity of oil cooled transformer the magnetic field strength was up to 10 A/m, the exception being, as mentioned, the area strictly located under MV busbar from the power transformers.

Therefore, the attention should be focused to electric field assessment. First of all it must be mentioned that the action value for professional exposure at power frequency electric fields is 10 kV/m (for public exposure the maximum value can't exceed 5 kV/m). Regarding the electric field strength, in four air insulated substations were explored a number of 11 main access paths (summing approx. 1,000 m) and the maximum measured values can be summarized as: on a single path – 4.87 kV/m; on four paths values ranging between 3.22....3.47 kV/m and on six paths values ranging between 1.25....2.68 kV/m. Electric field distribution on an access path in a substation is shown in Figure 1.

The measurements were performed at 1 m above ground level. In the points where was detected the maximum value at 1 m, there were performed measurements at three heights (as specified above) and was calculated the "exposure level" as average of the three values. In the 110 kV air insulated substations the measured non-uniformity degree was between 14% and 28%, but generally, the exposure level determined as average of three value was very close of the measured value at 1 m (the differences was of only few percent, in the limits of measuring uncertainty of equipment).

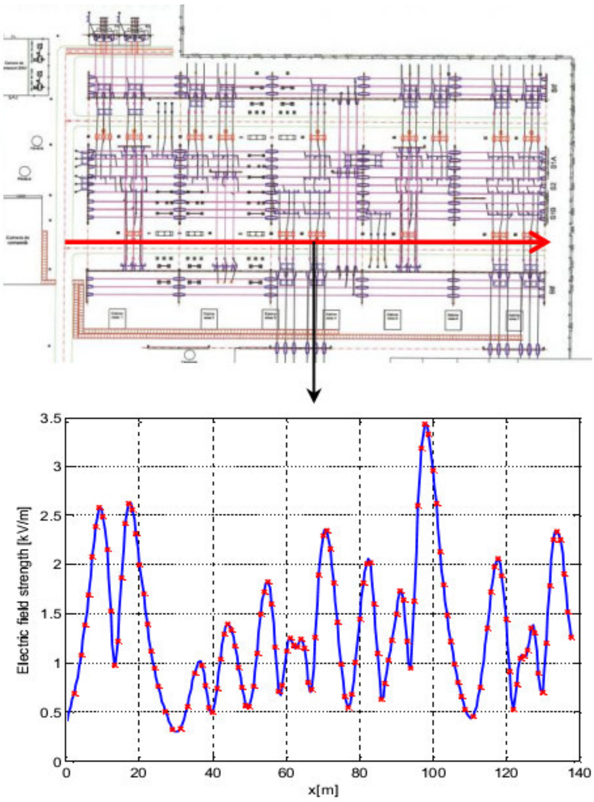

Figure 1. The measured electric field distribution on an access path (marked on the top view of the substation).

Around outdoor transformer substations (mounted on pole) and connected to overhead lines of 20 kV, the measured values were up to 50 V/m.Usually, under 20 kV overhead lines the electric field strength is up to about 120 V/m but the metallic parts of transformer substation acts as an electric shield and reduces, near the ground, the recorded value. Thus, even for large public the recorded values are under the admissible exposure limits.

5. MEDICAL CONSIDERATIONS

As it is well known, the interaction between the electromagnetic fieldsand theliving organisms has different consequences according tothe characteristic parameters and to the frequency range ofthe electromagnetic fields.

The values of the electric and magnetic field become restrictiveparameters, that should be taken into consideration in the activity of designand implementation ofelectrical equipment.

Parameters that highlightthe directbiological effects of the electromagnetic field on the human body beardistinct names in the mentioned documents, issued by the European Council. Regarding occupational exposure, the values which cause biological effects are called 'limit values of exposure', and the measurable ones, 'action values'. In the case of public exposure, the values which cause biological effects are called 'basic restrictions', and the measurable ones 'reference levels'. The monitoring of the exposure dose of the personnel to the electric field, allows assessing the risk posed by a particular job.

The international standards settled limit values ofthe characteristic parameters regarding the exposure of the human body to the action of the electric field produced near ground, by high-voltage electrical installations. The human body has been considered so far to not be affected by the values under 5kV/m.

On the ground level, under the high voltage transmission lines, in the areas where the electric field strength reaches the maximum, the value of 10kV/m, imposed by design, will not be exceeded. The occupational exposure time to this field strength must not last more than few hours. A great number of rules require the limiting of current densityinduced by theenvironmental electric field at a level of up to 10 mA/ m². This valueis considerably lower than the level of stimulation of nerveand muscle tissues that is of 1000 mA/m².

The study of biological effects of the exposure to the electric field requires the knowledge ofelectric currentinduced in thebody and itsdistributionin differentparts of the body.

The biological effects of human body exposure to the magnetic field are differentiated according to the exposure time:cumulative, for the long-term exposure and acute, for the short-term exposure [7,8].

As regards the exposures with cumulative effects, the significantcharacteristic parameter is the dose of magnetic field acquired by human body during large time periods. The dose of magnetic field is defined as the product between the magnetic induction *B* and the time *t* of human body exposure to the magnetic field.

The research onbioelectromagnetic is based on experiments that highlight itspossible negative effects or, on the contrary, the potential therapeutic effect, for example the controversial therapies in oncology developed by Antoine Priore and the therapy of old fractures with a difficult evolution ,with the aid of low-frequency electromagnetic radiation through the techniqueinitiated by theresearcher Andrew Bassett (Bassett et al. 1974, 1977, 1981, 1989) [9]. Nowadays it is recognizedthe role oflow-frequency electromagnetic fields in orthopedics, including the positive results in Parkinson's disease therapy (Rosch, Markov 2004).

The limits of the magnetic fieldexposure were settled by World HealthOrganization and International Commision on Non- Ionizing Radiation Protection [1]. In Occupational studies, the type of workperformed byelectricians determines different exposures to the electric and magnetic field and, consequently, differentriskfactor. The automation of the electricalprocesses from substations(SCADA -the remotemanagement of the installations, equipment without maintenance or with reduced maintenance) or the use of advanced technologies to control powerlines (e.g. thermovision) determines the reduction of workers' exposure time and thus the reduction of risk factors.

At the moment there are no results for the monitoring over long periods oftime (years) of the human body exposure to the electric and magnetic field, produced byelectric power distributionfacilities.

The effects of long-term exposure of the human body to electric and magnetic fields of low frequencyrequire systematic interdisciplinary studies, until now the results not being conclusive.

6. CONCLUSIONS

The measuring campaign regarding low frequency fields in some Romanian substations and transformer substations belonging of power distribution system (with rated voltage up to 110 kV) led unequivocally to the conclusion that the limit values, established by regulations relating to occupational exposure, are not exceeded. Moreover, in the large majority of measuring points are not exceeded even the limits for public exposure.

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