EMF EXPOSURE OF WORKERS IN ELECTRIC DISTRIBUTION AND GENERATION SYSTEMS IN REGARD TO DIRECTIVE 2004/40/EC SAFETY REQUIREMENTS – IS THERE A NEED TO TAKE ACTIONS?

Andreas ABART
EnergieAG OÖ - Austria
andreas.abart@netzgmbh.at

Ernst SCHMAUTZER
TU Graz - Austria
schmautzer@tugraz.at

Gerald WALLNBERGER
ÖBB - Austria
Gerald.wallnberger@oebb.at

Emil BITSCHNAU
Vorarlberger Illwerke AG
emil.bitschnau@illwerke.at

ABSTRACT

The directive 2004/40 EC requires the evaluation of working environment concerning EMF exposure of workers and measures in case conditions of the directive are not complied. This paper focuses on defining a substantiated efficient way of evaluation by non experts. Examples of measurements are presented. In few cases workers have to be instructed to avoid exceedance of limits by their behaviour. Probably some signs and cordons will have to be installed.

INTRODUCTION

The discussion about extremely low frequency magnetic fields in regard to possible health hazards especially cancer continues since almost 30 years. In summary the results of lots of studies is that a possible small risk might exist – which can neither be proved nor be disproved. The scientific evaluation is very complex to understand and the individual perception often leads to uncertainty and in some cases to fear. Under these circumstances authorities and technical committees have to come to decisions about limitation of exposure ensuring on the one hand an adequate precaution and on the other hand limited efforts and costs. The basis for the definition of safety requirements as e.g. done by ICNIRP is still the knowledge about induced current densities and heating effects. In general a more or less useful process of decreasing limits can be observed.

The DIRECTIVE 2004/40/EC [1] adopted the concept of the ICNIRP 1998-Guidelines by defining the reference values as “action-values” and basic restrictions as “exposure limits”. Some national standards, laws, decrees or directives have been providing for the case of short term exposure (e.g. < 2 h) up to tenfold higher limits. But the directive only contains limits to be applied to long term exposure as well as to short term exposure at the same level of earlier long term exposure limits. If exposure exceeds the action-value compliance to the directive can be proved if the induced current densities do not exceed the exposure limit.

In electric distribution and generation systems are some areas where “action values” given by the directive are exceeded. These areas can be found by doing exemplary measurements close to conductors leading very high or non-sinusoidal currents. The realization of the directive requires procedures of evaluation which can easily be picked up and used by the present staff of plants and stations who are not experts in electromagnetic fields. For reducing the efforts to a practicable way a handbook for EMF-evaluation will be designed.

A CONCEPT FOR EVALUATING COMPLIANCE TO THE DIRECTIVE

Methods for Magnetic Field

Several measurement results support the experience that exposure in areas close to generators and transformers is right beyond the action values. The distance from the surface was 0.3 m according to the draft of IEC 62110 (“Measurement Procedures of Electric and Magnetic Field Levels Generated by AC Power Systems with Regard to Human Exposure”). This standard further recommends the whole body exposure evaluation by calculating the average of flux densities in heights of 0.5 m, 1.0 m and 1.5 m. This could be applied if the distance to wires is very small and evaluation results without averaging exceed the action values. If a coil without a core causes exposure to be evaluated the current of the coil has to be multiplied by the number of windings. For areas in the vicinity of generators and transformers themselves there is no need for evaluation as exemplary measurement results clearly demonstrate. But lines connected to those machines have to be regarded in the evaluation process. If all phases together or each phase separately is installed in metallic pipes or casings the magnetic filed is reduced by eddy current effects which cannot be included in simple evaluation processes.

Simple 1st Step of Evaluation

The simplest approach for evaluating lines is of course amperes law resulting in 0.2 mT/kA at a distance of 1 m (inversely proportional to distance). Eq.1 defines the condition for fulfil the directives criteria of compliance.

$$2 \cdot \frac{I}{d} \cdot 10^{-7} < \textit{Action Value} \quad \text{eq.1.}$$

For 50-Hz-magnetic fields the action-value is 500 µT and eq. 1 results into the very simple condition of eq.2. In case of harmonic currents a correction factor is needed to verify compliance with directive. In case of simple 50-Hz-current this factor is 1 and less in case of harmonics. If the harmonics levels are well known the factor can be calculated (see below) and for public distribution grids representative factors have to be defined based on measurements of current.

$$I_{rms}(50Hz) < 2500 \cdot d \cdot k_{harm} \qquad \text{eq.2.}$$
$$I_{rms}(16\tfrac{2}{3}Hz) < 7500 \cdot d \cdot k_{harm}$$

As for $16^2/_3$-Hz-magnetic fields the action value is 1500 the limiting condition defined by eq. 2 is three times higher.

In Austria according to EN 50110 [3], “Operation of Electrical Installations” approximation to high-voltage-lines without insulation within a well defined zone is not allowed for workers anyway. These safety distances, including moving of e.g. the hand ensure at voltages up to 1 kV a distance of 0.5 m, above 1 kV 1.5 m, above 30 kV 2 m, above 110 kV 3 m and above 220 kV 4 m. That means that in case of non insulated installations of lines at operational currents below 3,75 kA (50 Hz, U>1 kV) up to 10 kA (50 Hz, U > 220 kV) no evaluation process is needed. This of course can not be applied in countries where workers get close to not-insulated-high-voltage-lines wearing insulating cloths or if insulated cables can be close to the workers body.
If the verification of compliance with conditions of the directives fails by using this simple first step of evaluation the second step, can be applied.

2nd Step of Evaluation
The second step of evaluation is still an easy process which can be applied by someone who is not an expert in analyzing magnetic fields. Unlike Step 1 all wires of a three-phases-system are regarded where resulting magnetic flux density levels are pretty lower because of the compensation effect by different phase currents. The flux density along a line of field points results from geometry and direction of the three parallel wires. The magnetic flux density maximum of course is at the surface of the wires thus regarding the exposure at field points of lines ending at the centers of the wires is a worst case analysis. Typical geometries of three-phase systems are triangle and row. Figure 1 shows the lines of field points selected for the worst case analysis.

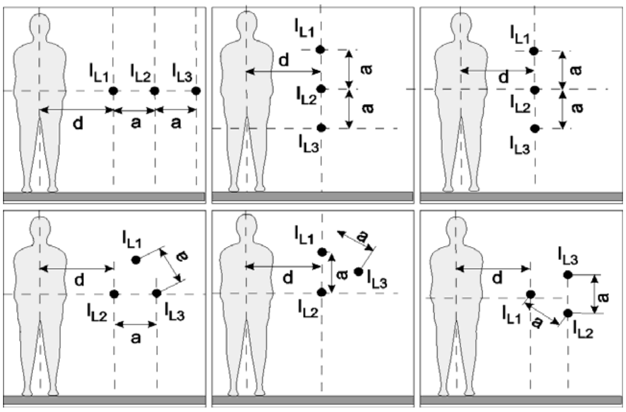

Figure 1: Selected geometries and lines of field points for the exposure worst case analysis

Figure 2 and Figure 3 are presenting maximum values of the calculated flux densities for the geometries presented in Figure 1. The values where calculated by superposing results from Biot-Savarts law for each wire. The double logarithmic scaling in Figure 2 and Figure 3 clearly demonstrates that the characteristic of the magnetic field is dominated in the proximity by the single wire characteristic given by eq.3 and for larger distances by eq.4.

$$\frac{B[\mu T]}{I[kA]} = \frac{1}{d} \cdot k_1 \quad \text{eq.3} \qquad \frac{B[\mu T]}{I[kA]} = \frac{a}{d^2} \cdot k_2 \quad \text{eq.4}$$

$B[\mu T]$...magnetic flux density $I[kA]$...current
$d[m]$...distance between fieldpoint and the closest wire
$a[m]$...distance between wires $k_1, k_2[]$...factors

As the results of eq.4 exceed those of eq.3 close to the system, whereas the area of proximity is determined by the distance between the wires, for evaluating compliance with action-values by using eq.3 and eq.4 for each field point the equation with lower result has to be applied. The factors in eq.3 and eq.4 are calculated from the results in figure 2 and figure 3 for row and triangle geometry.

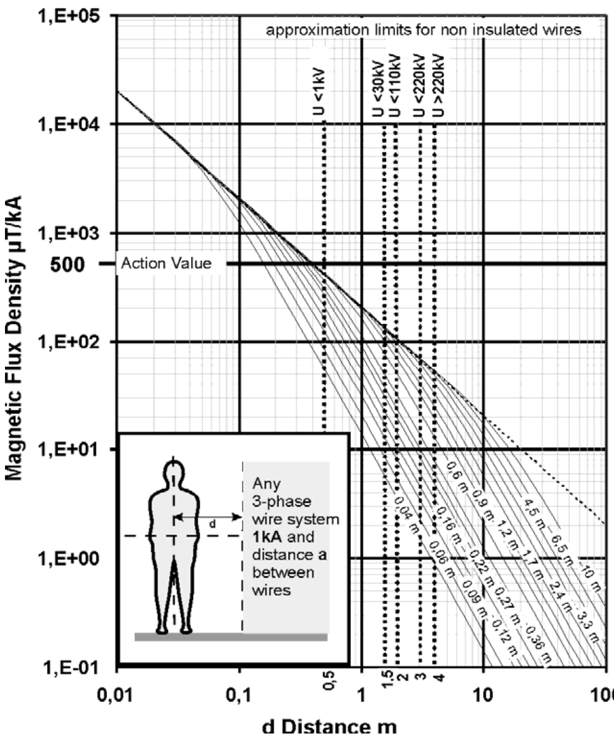

Figure 2: Calculated maximum values of magnetic field exposure for a 3-phase line with row geometry dependent from distance a between wires

Eq.5 to eq.8 are easily to apply. Thus none experts can perform this second step of evaluation. If the results of these equations are exceeding the action value but stay below 200%, the calculated values (figure 2 or figure 3) can be used. These results are below the equations results. In practice for well documented evaluation calculated values should be taken from tables.

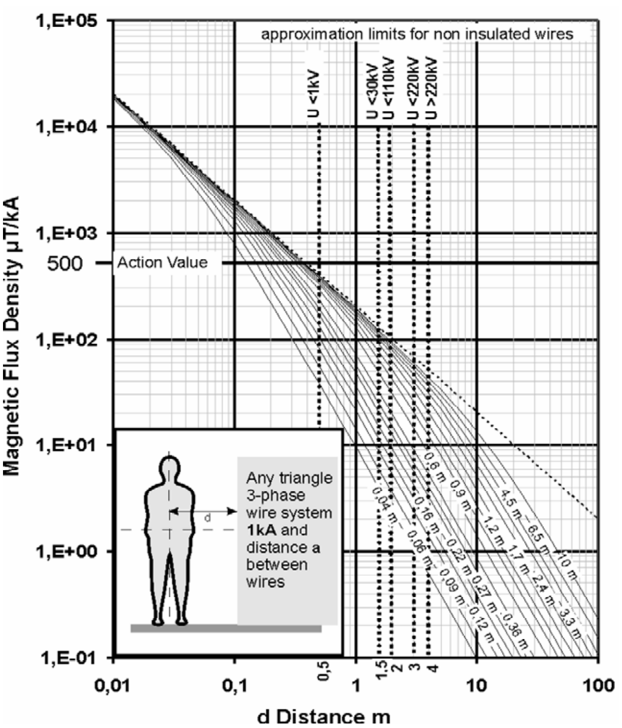

Figure 3: Calculated maximum values of magnetic field exposure for a 3-phase line with triangle geometry dependent from distance a between wires

Row: if $\frac{a}{d} \geq 0{,}57$ then $\frac{B[\mu T]}{I[kA]} = \frac{1}{d} \cdot 200$ eq.5

if $\frac{a}{d} < 0{,}57$ then $\frac{B[\mu T]}{I[kA]} = \frac{a}{d^2} \cdot 350$ eq.6

Triangle: if $\frac{a}{d} \geq 0{,}83$ then $\frac{B[\mu T]}{I[kA]} = \frac{1}{d} \cdot 200$ eq.7

if $\frac{a}{d} < 0{,}83$ then $\frac{B[\mu T]}{I[kA]} = \frac{a}{d^2} \cdot 240$ eq.8

If there are harmonic currents in the system they have to be considered and included in the verification of compliance of the exposure to the action values of the directive as defined in the directive (table 1).

Frequency range	Electric field strength, E (V/m)	Magnetic field strength, H (A/m)	Magnetic flux density, B (µT)	Equivalent plane wave power density, S_{eq} (W/m^2)	Contact current, I_C (mA)
0 – 1Hz	–	$1{,}63 x 10^5$	$2 x 10^5$	–	1,0
1 – 8 Hz	20000	$1{,}63 x 10^5/f^2$	$2 x 10^5/f^2$	–	1,0
8 – 25 Hz	20000	$2 x 10^4/f$	$2{,}5 x 10^4/f$	–	1,0
0,025 – 0,82kHz	500/f	20/f	25/f	–	1,0
0,82 – 2,5 kHz	610	24,4	30,7	–	1,0
2,5 – 65 kHz	610	24,4	30,7	–	0,4 f
65 – 100 kHz	610	1600/f	2000/f	–	0,4 f
0,1 – 1 MHz	610	1,6/f	2/f	–	40
1 – 10 MHz	610/f	1,6/f	2/f	–	40

Table 1: frequency dependent "Action Values" as defined in directive 2004/40/EC []

3rd Step of Evaluation

If even the second step does not prove compliance exposure the exposure situation has to be analysed by an expert using adequate calculation and measurement methods. In many cases calculation and measurements methods are complementing each another.

Exposure Analysis Examples

170 MVA Power Station: According to 2nd step the evaluation of a 7 kA current (without considering the coating iron pipe, diameter 1 m) at a distance of 0.8 m results to 1750 µT (exceeding 350 % of action value). In fact except at two field points the measured and extrapolated to rated current (I_N) magnetic field exposure is much lower (figure 5). The measurement is performed by using a positioner for the probe. The positioner provides following the draft of IEC 62110 [4] three positions in the height of 0.5, 1 and 1.5 m at a distance of 0.3 m to the surface of coating elements (pipe, cases etc.). The measured magnetic flux densities at the generators surface do not exceed 50 µT. The measurement does not show any harmonic currents. Thus these results demonstrate that unlike the vicinity of the main generator lead the magnetic field in the surrounding of the 170 MVA generator (figure 4) is below 10% of directives action value. Results of some other measurements in the vicinity of transformers, gas isolated stations etc. are similar.

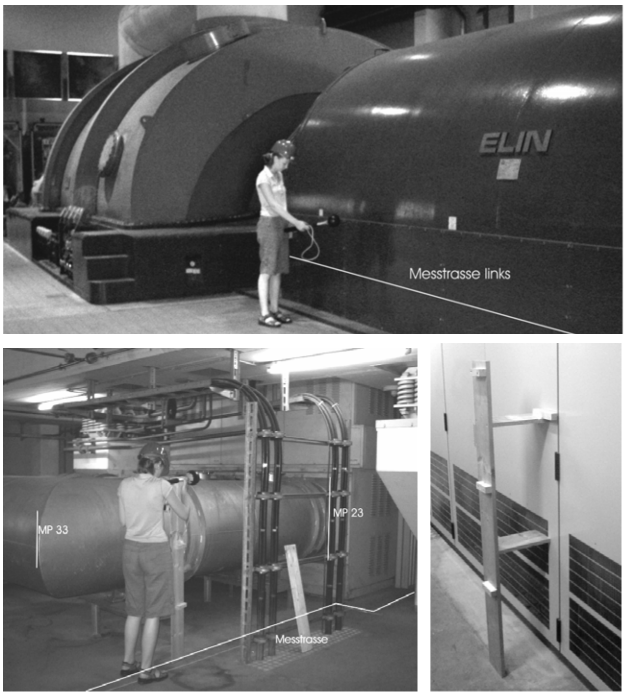

Figure 4: left: 170 MVA generator and 7 kA line coated with iron pipes. Right: probe-positioner

As a measure in the area of exceeded action values, which is situated between a pillar and the connector unit, a direction sign to pass the pillar on the right hand side where directives conditions are complied will be installed.

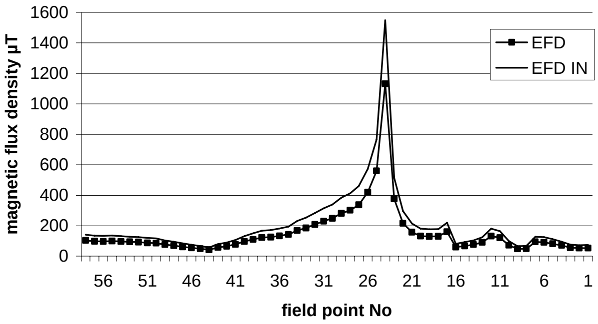

Figure 5: Measured exposure along the generator lead coated by an iron pipe (figure 4, bottom picture left)

60 kV UPS: Among the measurement results the example of a 60-kVA-UPS with an almost 30 years old ac-converter is of interest in respect to harmonic currents. The positioner was used along the surface of the switch cabinet. Figure 6 shows the characteristic of the flux density rms-value in contrast to the percent of action value line. The field points where results are exceeding action values are not those where maximum rms values appear because a high harmonic ratio can cause higher eddy currents densities in the human body. Increasing the distance from 0.3 m to 1.1 m reduces exposure to complying values. The measures in this area - introducing workers and installing sings - do not cause much effort.

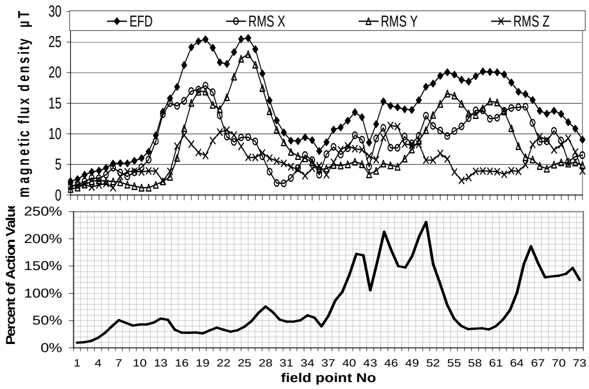

Figure 6: characteristic of the magnetic field (rms and % of action value) in front of a 60-kVA-UPS-switch cabinet

Methods for Electric Field

The directive defines 10 kV/m as the action value of the electric field strength (50 Hz). The ICNIRP98’ Guidelines recommend 10 kV/m in case of occupational exposure and 5 kV/m for the general public corresponding with a current density of 2 mA/m². For occupational exposure ICNIRP defines 10 mA/m² as the basic restriction (this is called exposure limit in the directive). Because of this 5-fold-factor compliance to the exposure limit of the directive can be argued at 25 kV/m. The calculation of electric fields in stations and working environment means some effort in modelling. In general measurements are sufficient.

Experiences with measurement results of electric field strengths in 220/380-kV-outdoor stations do not exceed 12 kV. Figure 7 shows an area in a 220-kV-station where lines are closest to ground.

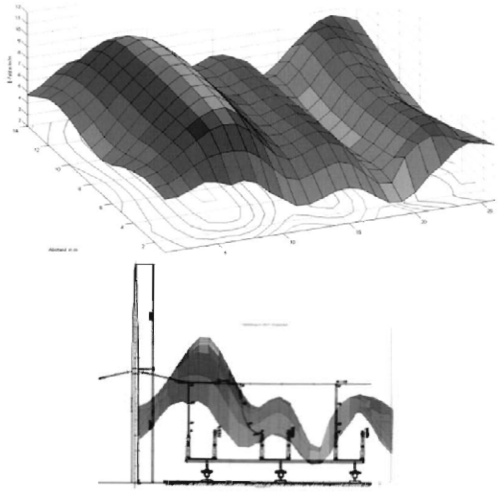

Figure 5: Measured distribution of electric field strength in a 220-kV-station

CONCLUSIONS

The answer to the question in the title is: yes, there is a need to take few actions. Most effort will be the evaluation including training and organization. Only few exposure situations will require measures to avoid exposure above the action values. From the actual point of view no reconstructions in power plants and stations are expected. The workers behaviour has to be adopted a little bit by introductions and some areas have to be marked. The main reason for widely existing compliance to the directive is that the action value is equal to the long term limit defined in the specific Austrian standard since almost 20 years. Only harmonics where considered less detailed than today, probably because adequate measurement systems where not available before.

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