OCCUPATIONAL EMF-EXPOSURE: A SIMPLE GUIDE FOR TESTING COMPLIANCE WITH REQUIREMENTS OF DIRECTIVE 2013/35/EU

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ABSTRACT

The EU-Directive 2013/35/EU [1] for protection of workers from exposure to electromagnetic field was implemented in Austria by national decree in 2016 – VEMF [7]. To avoid a diversity of methods for EMF evaluation a national guideline R27 providing efficient assessment procedures for electricity supply systems, elaborated by an expert group of OVE (Standardization of electrotechnics), will be published soon. Simple formulas and tables containing minimum distances for compliance and relevance, based on worst case parameters are supporting a quick assessment avoiding large efforts of data acquisition in detail. Expert's work for measuring and calculating exposure is thus needed only in specific cases of special configuration or in case of high exposure, when R27-methods fail to demonstrate compliance with action levels of 2013/35/EU.

The first step of assessment of a working area is based on a concept for classification of EMF-zones with different levels of protection regarding general public, employees and young apprentices according to ICNIRP 2010 [3]. The national decree requires to comply with the safety requirements of council recommendation 1999/EG/519 [5] equal to ICNIRP 1998 [2] for pregnant workers and with EN 50527 [9] for persons with AIMDs. For exposure of general public in Austria there is no decree but a national guideline as state of the art, published by OVE in 2016. To achieve a minimum of restricted access the most sensitive zone should be classified for most parts of the area. Within the second step for each EMF-zone PoPs (Points of Proof, field points supposed to show maximum exposure) have to be defined. For each PoP the compliance with required limits for the action levels is tested. Once the compliance of all PoPs has been proven, the compliance of the whole area can be concluded.

INTRODUCTION

In Austria the national implementation of the European Directive 2013/35/EU is the decree VEMF [7] published by the Austrian Government in 2016. For young workers (less 18 years or less than 18 months of apprentice training) and cases of pregnancy or people with active implanted medical devices the requirements are more restrictive than 2013/35/EU ones. Young workers and pregnant workers have to be protected by ensuring compliance with the EU-council recommendation 1999/EG/519. For persons with active implanted medical devices an additional edict [8] requires exposure below a level where electromagnetic interference can be assumed as unlikely according to actual readings.

The national decree VEMF requires to perform a documentation of EMF-exposure assessment within the workplace evaluation. It is not sufficient to perform exposure assessment only for those areas in which compliance with the decree can not be expected.

The association of Austrian utilities has developed common guidelines for occupational safety. Since 2012 a taskforce studied possibilities for applying the directive in practice. The result of this work is a set of simple methods of exposure assessment to be applied by safety engineers with only basic knowledge about electric and magnetic fields. Especially complex cases with multiple sources and time variant currents are covered. For most areas, the compliance can be demonstrated by applying these methods. Thereby, areas to be analysed by experts are identified. The main targets of these methods are the simplicity as well as the applicability in respect to required time, documentation and replicability. All these targets support the minimization of economic strain.

Following the publication of the evaluation methodology in the utility's guidelines at the end of 2017, a working group of the Austrian National Standards Committee (ANC) started drafting a national guideline to be published in 2019. The expert group agreed, that for assessment of energy supply systems in grids, buildings, industry and for railways the consideration of exposure in the frequency range up to 100 kHz is sufficient. Therefore, the evaluation of the thermal effects for energy supply equipment is not required.

METHODS OF EXPOSURE ASSESSMENT

For assessment electric and magnetic field levels are compared to the given so-called action levels AL [1]. The nomenclature "action level" in this work is also applied on the reference values given by ICNIRP [2,3], and EMC limits for pacemakers given by EN 50527 [9].

EMF Zones

Employees are permitted to be exposed to electric or magnetic fields at different levels, depending on age, case

of pregnancy and electromagnetic immunity of active implanted medical devices (AIMD). As a first step a concept of zones for the workplace is defined. In all areas to which every employee has access, the reference levels for protection against EMF in accordance with ICNIRP 1998 must not be exceeded. Table 1 shows the R27 zone classification for different categories of employees. The action levels for exposures with frequency 50 Hz are given as an example.

Table 1: classification of exposure zones

Zone	Action level (AL) or limit	AL elec. kV/m	AL mag. µT	Restricted access for
0	1999 /519/EG	5	100	nobody
A	Reference levels acc. to ICNIRP 2010	5	200	• Pregnant • Persons with AIMD
B	Action levels according to 2013/35/EU	10/20	1000	• Pregnant • Persons with AIMD • Persons with-out instructions
C_s	Exposure limit sensory			• Pregnant • Persons with AIMD • Persons with-out instructions • Young workers
C_h	Exposure limit health AUT decree: Only in specific cases if no reduction is possible			• Pregnant • Persons with AIMD • Persons with-out instructions • Young workers
X	Exceeding exposure limits for employees			All persons

To get a zoning plan the proof of compliance has to be furnished for each zone of the zoning concept according to table 1. The workplace evaluation is based on the zoning plan thus it has not to be elaborated by the same person performing the evaluation. Fig. 1 shows the flowchart of the procedure.

Proofing compliance for EMF Zones

Each EMF-zone of the zoning plan is deemed to comply with the requirements of the classification in any point of its space. The proof of compliance is performed for a limited number of points to be selected by considering supposed maxima of exposure. The number of Points of Proof (PoP) should be reduced to the necessary minimum. These PoP are located for example closest to the source with the maximum voltage for the assessment of the electric field and with the maximum current for the magnetic field. Every source inside and outside the zone must be considered.

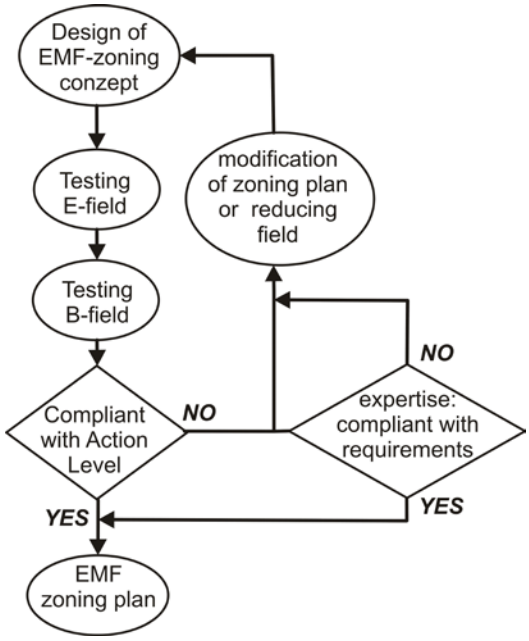

Figure 1: Flowchart for the elaboration of a zoning plan

For sources outside the zone the PoP has to be located at the border of the zone. For each PoP the sources, which are relevant for the assessment have to be identified. In case there is only one source, there is a certain distance – the so called Action Distance (D_A) –for each zone's action level being exceeded when distance is lower than the Action Distance

The expert group elaborating R27 agrees to a threshold level for relevance at 20 % of AL for magnetic field assessment and at 50 % of AL for the electric field. For each source, there is a certain distance where exposure exceeds 20 % of action level – the so-called Relevance Distance D_0.

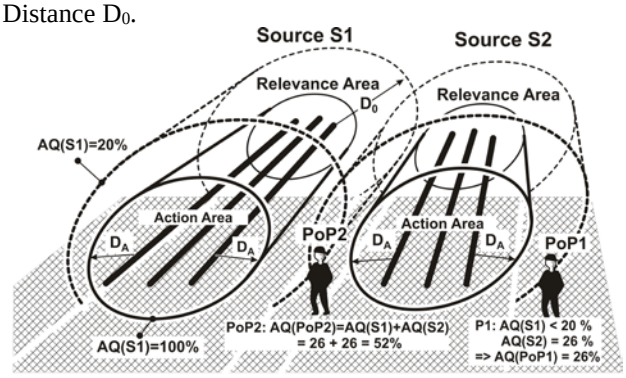

Figure 2: Example for Action area and relevance area and superposition of two relevance areas.

The concept of Relevance Distance is the key for checking sources for relevance. Check radiuses for different classes of sources are calculated from the relevance distances.
The maximum check radius for the coupling conductors of two busbars as part of an air-isolated 400-kV-station for zone 0 results in 29 m. For setting the PoPs in a zone 0 area

PoPs have to be located closest to sources inside the zone (0.3 m to the surface or housing and at safety distance in case of non-isolated parts) and the surroundings of the zone has to be checked for sources within the check radius. If there is no source within 29 m distance (zone 0) from the zone's border there is no relevant contribution to the exposure from outside the zone. For types of sources with lower emissions than the coupling of 400-kV-busbars the resulting check radiuses are much lower. For example, the check radius for a 0.4-kV-distribution box in a building with a rated current of 250 A results in less than 1 m.

In many cases it seems easy to measure and evaluate the electric and magnetic fields. This is correct for electric fields and magnetic fields caused by one source in case the maximum exposure can be investigated by extrapolation from the state of operation during measuring up to maximum.
Stations in transmission systems and substations or distribution boxes in public grids or in buildings can be understood as a couple of sources with different time behaviour. If there is a possibility to operate each single feeder the action quotient AQ (ratio of measured field and action level) can be detected and the total AQ can be calculated by summation.

In many cases of grids, buildings or industry a well-defined operation of single feeders cannot be assumed. Thus, the only method for assessment is the worst-case calculation of magnetic field. To avoid large efforts for detailed modelling for the assessment of magnetic field simple models shown in figure 3 are used (see also Paper 2119).

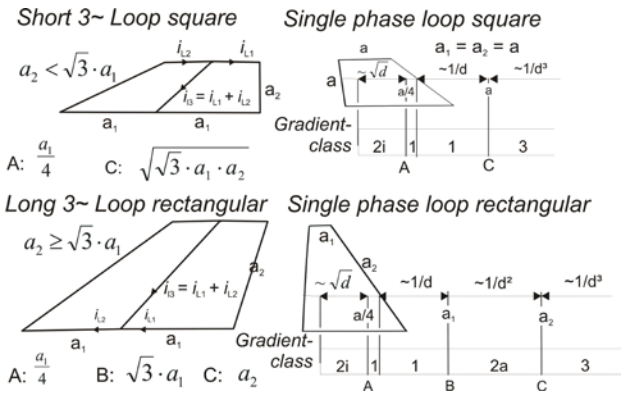

Figure 3: simple models of plain loops are replacing complex 3-D structures

Complex 3-D-structures of conductors are reduced to simple rectangular loops. In the surrounding of these loops in respect to the decrease of exposure depending on distance d three different areas can be classified: ~ 1/d, ~1/d², ~1/d³.

Figure 4 illustrates this characteristic decrease (gradientclasses) of magnetic flux density.

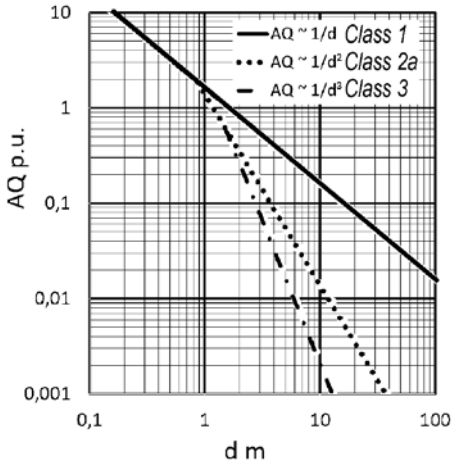

Figure 4: Gradientclasses for characteristic decrease of magnetic flux density

The formulas for these simple models still require acquisition of more or less detailed data. To avoid efforts of data acquisition the R27 guideline provides a set of parameters for typical implementations of installations for different voltage levels and environments e.g. public grid, railways, buildings, industry also including the consideration of harmonics to evaluate the worst-case exposition of employees.

Testing compliance for PoPs

According to the flowchart shown in figure 5, for each PoP (Point of Proof) the surrounding sphere with the radius of the value of the check radius dependent on the type of source is checked for sources. The steps in figure 4 result in the evaluation of exposure where the sum of all action quotients, the total AQ has to be calculated. It should be less than 100%

The flowchart for the evaluation of electric fields is similar to the flowchart for the magnetic field.

In case compliance cannot be demonstrated according to the flowchart in figure 1 there are two different possibilities: Either an expert assesses exposure with more detailed analysis, which typically result in lower exposures or if possible simple measures for increasing the distance to the source or reducing the emission are undertaken.

Example for elaborating a zoning plan

Figure 6 shows a small and simple primary substation with busbars above the feeders to be assessed in respect to worker's exposure against EMF for the workplace evaluation. This substation is inside a fence where the zoning concept defines outside the fence the zone 0 and inside the zone A for footpaths and zone B in the vicinity

- Definition of PoPs (Points of Proof) where exposure is supposed to be maximal
- Identifying sources within the check radiuses
- Testing relevance of sources by comparing currents and voltages with relevance levels
- In case only one relevant source is detected within the check radius:

  Testing of action distance D_A (calculation or reading from R27 table)
- In case more than one source within the check radiuses are detected:

  Analysing the relevance distance D_0 for each source (calculation or reading from R27 table)
- Evaluation of AQs for all relevant sources
  - Measurements, calculations or reading from R27 tables of magnetic flux density for the PoP
  - Summation of all action level quotients in case of multiple sources
- Checking Compliance AQ < 1 ?

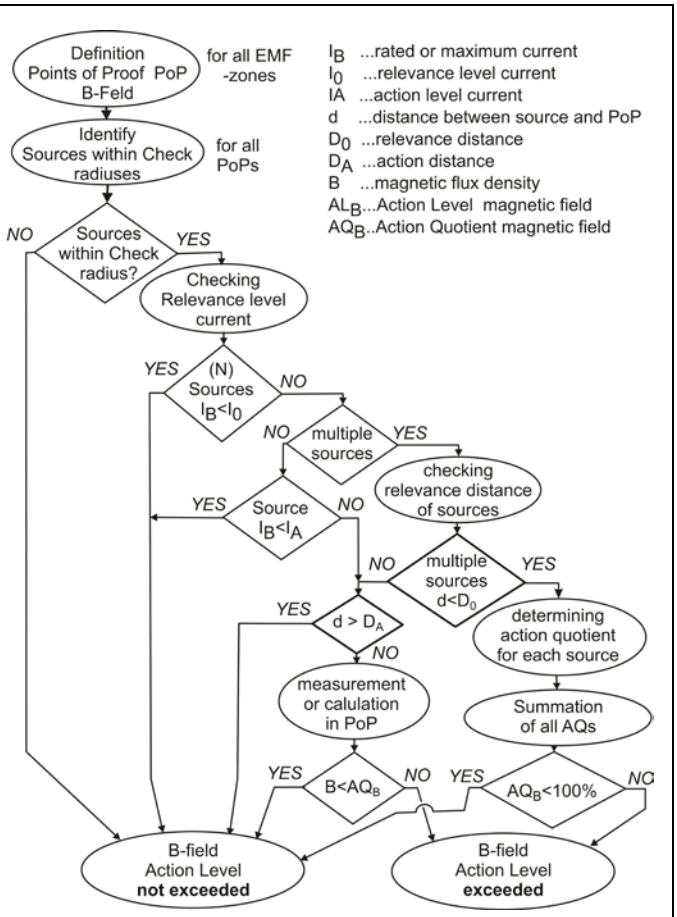

Figure 5: Procedure and flow chart for assessment of magnetic field exposure

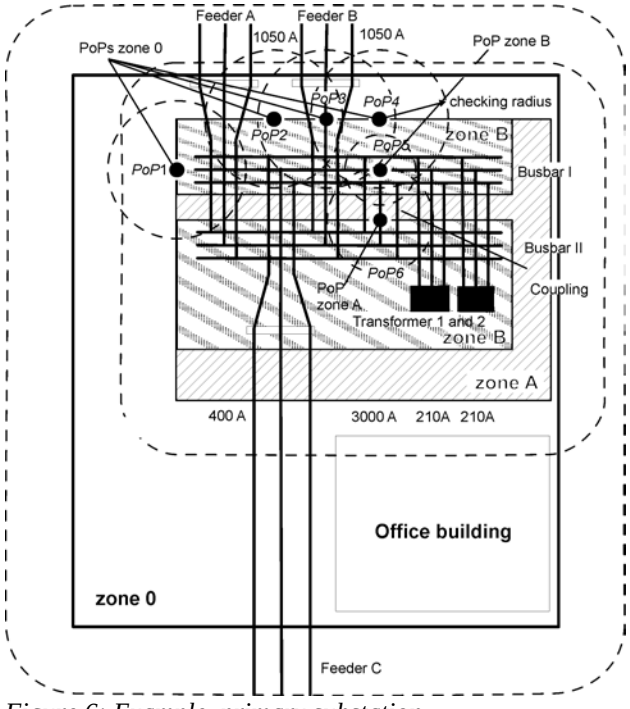

Figure 6: Example, primary substation

of busbar-, and switchgear elements. Only persons with safety instructions are allowed to stay in zone B. Restricted access by signs have to be implemented for persons with AIMD and pregnant women.

In case the area outside the fence is for public access, there is no need for consideration within the evaluation as it can be assumed that the safety limits are fulfilled

In figure 6 the PoPs for the zone 0 are located at the border to zone A or directly to zone B in case no zone A is in between. The PoPs are closest to the sources where maxima of exposure are assumed: typically central below the feeder B, between feeder A and feeder B, beside the feeder right to the coupling and one beside the busbar.

Table 2: relevant elements for each PoP

PoP No	**1**	**2**	**3**	**4**	**5**	**6**
zone	**0**	**0**	**0**	**0**	**B**	**A**
feeder A	7m	7m	-	-	-	-
feeder B	-	7m	6m	7m	-	-
feeder C	-	6m	9m	-	-	-
coupling	-	-	9m	8m	4m	4m
transformer 1	-	-	-	-	-	-
transformer 2	-	-	-	-	-	-
busbar I	7m	8m	8m	8m	6m	8m
busbar II	14m	-	-	-	-	6m

The PoP of zone A is at the border to B central below the coupling where maximum current is expected. The PoP for Zone B is below the busbar and coupling. The dashed line around the fence is the check radius for sources with possible impact in zone A and the dashed line around the company's area is the check radius (e.g. for 110kVairinsulated station: 15.5 m) for possible relevant sources from outside. The dashed circles around the PoPs indicate the check radiuses for the PoPs for identifying the relevant sources for the assessment. The different check radiuses are corresponding to different action levels, as the lower the action level is, the larger the check radius becomes.

Table 3: AQs of relevant sources in each PoP

PoP No	**1**	**2**	**3**	**4**	**5**	**6**
zone	**0**	**0**	**0**	**0**	**B**	**A**
feeder A	26%	26%	-	-	-	-
feeder B	-	26%	30%	26%	-	-
feeder C	-	-	-		-	-
coupling	-	-	30%	35%	-	50%
transformer 1	-	-	-	-	-	-
transformer 2	-	-	-	-	-	-
busbar I	262%	-	35%	35%	-	-
busbar II	-	-	-	-	-	30%
Sum of AQs	**52%**	**52%**	**95%**	**96%**	**<20%**	**80%**

Table 3 shows the results for all AQs. As the resulting total AQ for all PoPs is below 100 % the zoning concept can be used as zoning plan without any modification. By demonstrating compliance for the PoPs the compliance is demonstrated for all zones of all the company's area, as the choice of the PoPs is determined by expected peaks of exposure (worst case). There is no need for a PoP in the office building as the peaks of exposure in zone 0 are at the fence on the other side of the station as the other side is closer to the sources.

Thus, in case of larger stations probably the same number of PoPs is sufficient for assessment. For similar stations, the evaluation results can be made analogously.

CONCLUSION AND OUTLOOK

The method presented in this paper and actually implemented to the national guideline OVE-R27, which is planned to be published in spring 2019 provides an efficient and simple approach for evaluation of workplaces in respect to exposure against electric and magnetic fields caused by equipment of electric energy supply including distribution boxes and connection boxes.

The straight and systematic approach based on worst cases for typical maximums of rated currents and the typical voltages and worst geometric parameters in use the replicability of the assessment is quite good. The procedure does not require to be performed by persons who experts in the fields of EMF but nevertheless, a good documentation is necessary

For the construction of new stations and distribution boxes the presented method of "Action Distance" and "Relevance Distance" as well as the simple modelling will have impacts on the design. It can be expected that simple planning principles derived from this will in future support the minimization of electric and magnetic fields.

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