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# Magnetic Field Density Analysis in Switchgears

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**Abstract.** For many years the evaluation of the electromagnetic field (EMF) generated by transformer substations (TS) and switchgear assemblies has been an extremely cumbersome and expensive process. Manufacturers and users of TS and switchgear lacked a broadly-accepted assessment procedure specified in an international reference standard. The publication of the new Technical Report IEC/TR 62271-208 solves this situation since it describes a technique for the evaluation of the EMF generated by switchgear assemblies and TS and opens the possibility of employing simulation tools for this purpose.

In this paper, preliminary stage of process for validation of simulation tests in order to substitute laboratory tests according to IEC/TR 62271-208, is described. With this purpose, magnetic field emission analysis is carried out using finite elements (FE) method, for a set of 5 identical switchgears (manufactured by Ormazabal), in series connection. Results obtained through simulation are compared to those measured in laboratory tests. Evaluation results are also compared with applicable limits (100 μT and 500 μT at 50 Hz, according to most human exposure regulations: ICNIRP Guidelines, EU Council Recommendation, Spanish Royal Decree 1066/2001, etc).

## Key words

Finite elements method, human exposure, magnetic field, medium voltage, switchgear.

## 1. Introduction

In recent years, the electric and magnetic fields emitted by power lines, electrical equipment and installations have received a lot of interest from the general public, and as such no less attention has been paid by regulators, scientists, manufacturers and electrical companies. National and international regulations have set the limits of human exposure to these type of fields based on current scientific evidence and a precautionary principle. Nowadays most widespread international analysis on this issue, is published by International Commission on Non-Ionizing Radiation Protection (ICNIRP) [1].

European Union (EU), following advice from Scientific Steering Committee, elaborated the EU Council Recommendation on exposure of the public to electromagnetic fields of 0 Hz to 300 GHz frequency [2], which bases on ICNIRP Guidelines and aims to prevent acute effects (short term) caused by induction of electric currents in human body. In the case of power frequencies, EU Council sets a theoretic reference level for magnetic field (MF) at power frequency (50 Hz) in 100 μT and 500 μT for general public and occupational (workers) exposure, respectively.

In Spain is of the highest importance the technical report [3] issued by a committee of experts summoned by the Ministerio de Sanidad y Consumo. This report concludes that: “fulfilment of European Council recommendations is sufficient to guarantee citizens' health protection”.

Even when the limits are well specified, the assessment or testing methods remain unclear or are troublesome, at least with respect to medium voltage (MV) switchgear and TS.

Switchgear installations permanently produce power frequency electric and magnetic fields. Field levels depend on line voltage (electric field) and load conditions (magnetic field). Generated electric and magnetic fields are not limited to the very close vicinity of the current carrying conductors. However, in the case of the electric field, as most of the switchgear components are enclosed in earthed metallic encapsulations, the shielding elements lead to a drastic attenuation of electric field which means that, in general, electric field analysis outside the enclosure lacks of interest.

In many cases, the locations around switchgears are used for the installation of sensitive equipment, and the MF should be taken into account. In these cases the corresponding MF limits have to be analyzed at those locations to ensure magnetic field levels are below limits established by international standards and the manufacturer's provisions.

In the literature some techniques have been described to predict the MV switchgear MF [4-5].

The overall objectives of this paper are, first to explain the process used to measure in the laboratory at current rating, magnetic field density values in the surroundings of five switchgears, and second, to specify the method used for simulation of switchgear behaviour using the FE technique. Results obtained through both methods are analyzed and compared. In addition, the MF results obtained using FE method are utilized for comparison with applicable limits (100 µT and 500 µT at 50 Hz, according to most human exposure regulations). Implementation can be conveniently realized by using *EMS*, a commercially available FE package.

The resulting field distributions can be utilized to determine appropriate distances between switchgear and the areas under consideration in order to comply with any limits concerning people and equipment and it is a preliminary stage for the validation process of a FE simulation tool in order to substitute laboratory tests for magnetic field determination in TS, according to IEC/TR 62271-208 [6-7].

## 2. Description of the Assessed Switchgears

The analysis was performed on five MV switchgears (see Fig. 1) of CGM type, 24 kV, 630 A, 50 Hz, manufactured by Ormazabal [8] and in series connection. The overall external dimensions of the switchgears are 2.4 m length, 1.8 m height and 0.85 m width. The measurement and behaviour simulation is performed at current rating, with first and fifth switch in closed position and open state for the rest.


Fig. 1. Switchgears.

## 3. Magnetic Field Measurement

The measurement was performed in the Ormazabal laboratory in 2009, being the switchgears excited with three-phase balanced sinusoidal currents (630 A in this case). The magnetic flux density was measured at 144 points located 1.5 m above the ground plane and at rectangles separated 0.005, 0.5, 1, and 1.5 m from the metallic encapsulations of switchgears (see Fig. 2).

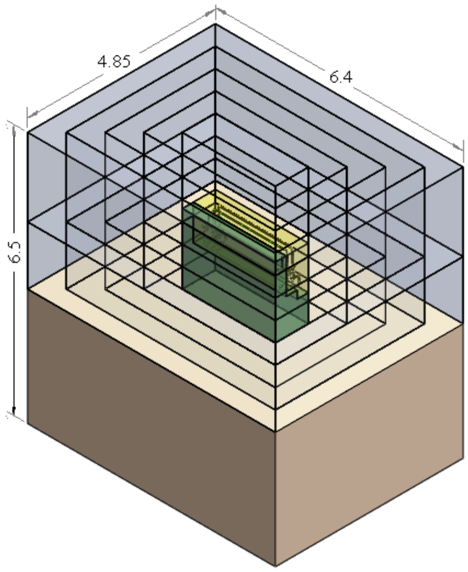
| | 1.500 | 1.000 | 0.500 | 0.005 | 0.000 | -0.425 | -0.850 | -0.855 | -1.350 | -1.850 | -2.350 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| -1.500 | 97 | 144 | 143 | | 142 | 141 | 140 | | 139 | 138 | 137 |
| -1.000 | 98 | 57 | 96 | | 95 | 94 | 93 | | 92 | 91 | 136 |
| -0.500 | 99 | 58 | 25 | | 56 | 55 | 54 | | 53 | 90 | 135 |
| -0.005 | | | | 1 | | 24 | | 23 | | | |
| 0.000 | 100 | 59 | 26 | | | Axis Z | | | 52 | 89 | 134 |
| 0.240 | 101 | 60 | 27 | 2 | | | | 22 | 51 | 88 | 133 |
| 0.480 | 102 | 61 | 28 | 3 | | | | 21 | 50 | 87 | 132 |
| 0.720 | 103 | 62 | 29 | 4 | Axis X | | | 20 | 49 | 86 | 131 |
| 0.960 | 104 | 63 | 30 | 5 | | | | 19 | 48 | 85 | 130 |
| 1.200 | 105 | 64 | 31 | 6 | | Switchgears | | 18 | 47 | 84 | 129 |
| 1.440 | 106 | 65 | 32 | 7 | | | | 17 | 46 | 83 | 128 |
| 1.680 | 107 | 66 | 33 | 8 | | | | 16 | 45 | 82 | 127 |
| 1.920 | 108 | 67 | 34 | 9 | | | | 15 | 44 | 81 | 126 |
| 2.160 | 109 | 68 | 35 | 10 | | | | 14 | 43 | 80 | 125 |
| 2.400 | 110 | 69 | 36 | | | | | | 42 | 79 | 124 |
| 2.405 | | | | 11 | | 12 | | 13 | | | |
| 2.900 | 111 | 70 | 37 | | 38 | 39 | 40 | | 41 | 78 | 123 |
| 3.400 | 112 | 71 | 72 | | 73 | 74 | 75 | | 76 | 77 | 122 |
| 3.900 | 113 | 114 | 115 | | 116 | 117 | 118 | | 119 | 120 | 121 |

Fig. 2. Magnetic field measurement points.

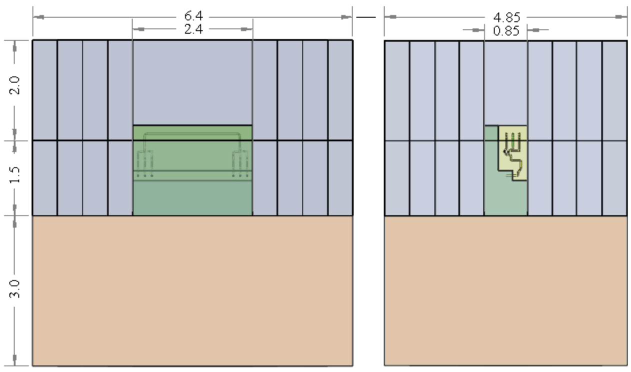
For the magnetic field measurement a receiver and a unidirectional magnetic field probe were used. During laboratory tests values of the three magnetic flux density components were measured for each measuring point, but only the highest component was recorded.

## 4. Simulation

FE technique is used for simulating the magnetic behaviour of the switchgears. The three-dimensional FE model (see Fig. 3) has five perfectly different parts: a) current carrying conductors (only current carrying conductors are included and the first and the last switch blades are represented by round section bars), b) area encapsulated by stainless steel sheet with SF6 isolation level (see Fig. 4), c) area enclosed by galvanized steel with air isolation level, d) space of air surrounding the switchgears, separated in different volumes for magnetic flux density measurements at locations defined in section 3, and e) an additional volume located below for adequate application of boundary conditions. The relative magnetic permeability of all materials is 1, except for galvanized steel, which is 100. Performed analysis is AC magnetic at 50 Hz.




a) 3D view




b) Front view    c) Right view

Fig. 3. The three-dimensional FE model.

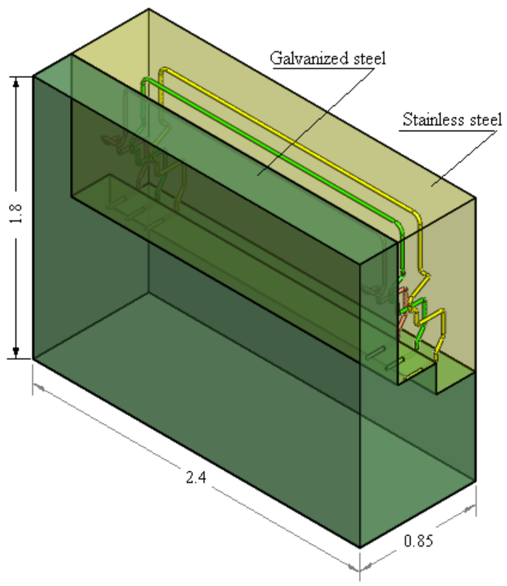


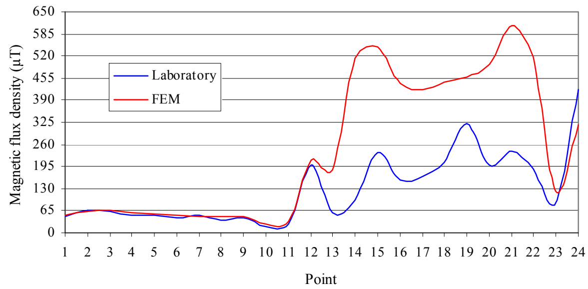

Fig. 4. Materials.

## 5. Results

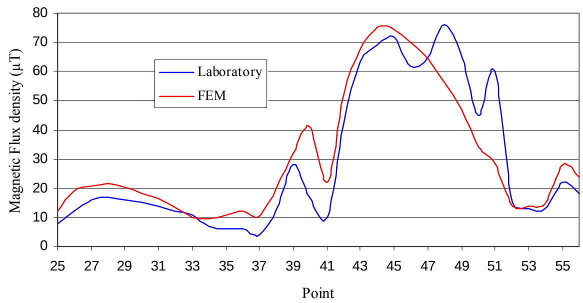
In this section, magnetic field density values measured in laboratory tests are compared to those obtained through FE method, and magnetic exposure volumes for 100 and 500 µT are defined.

### A. Magnetic flux density

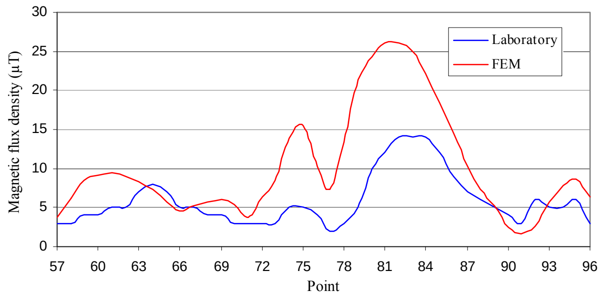
Figure 5 shows, for the measurement points defined in section 3, magnetic flux densities measured in laboratory tests and those obtained through the FE method.



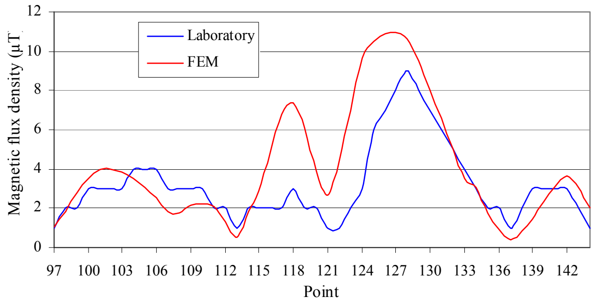

**a)** 1st rectangle, points 1 to 24 located at 0.005 m from switchgears.




b) 2nd rectangle, points 25 to 56, located at 0.5 m from switchgears.




c) 3rd rectangle, points 57 to 96, located at 1 m from switchgears.

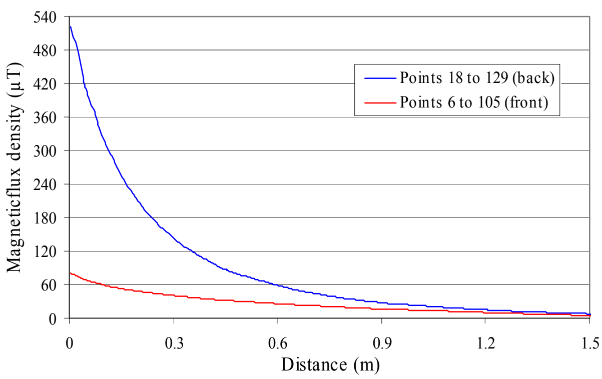



d) 4th rectangle, points 97 to 144, located at 1.5 m from switchgears.

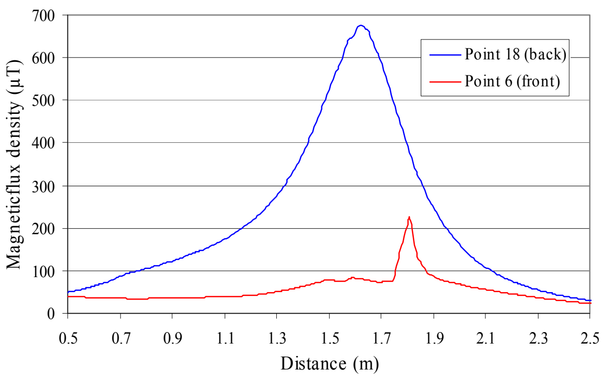
Fig. 5. Magnetic flux density, points in a plane located 1.5 m above ground.

It can be observed that the relationship between magnetic flux emissivity values measured in laboratory tests and values obtained through FE method shows good correspondence at measurement points located in the front side of equipment; however, correlation decreases at back side except for those points separated 0.5 m from equipment. Possible causes of error could be: a) measurements could have been taken at points different from those defined in section 3 (equipment back side has no magnetic shield, the enclosure material is stainless steel of relative magnetic permeability equal to 1, and slight differences of the measurement point position or distance from ground could bring important variations of magnetic flux density), b) measurement device accuracy (receiver and probe), and mainly orientation of the testing probe, and c) simplification of current carrying conductors' geometry (FE model).

Figure 6, as an example to justify above mentioned effect, shows magnetic flux density (resultant component) as a function of distance for the following cases: 6a horizontal direction measurement at points 18 to 129 (switchgear back side) and points 6 to 105 (front side), and 6b vertical direction measurement at point 18 and at point 6 from 0.5 m above the ground to 2.5 m height. We can observe that at back side and near point 18, magnetic flux density variation is important in horizontal direction (near 0 distance in Fig. 6a as much as in vertical direction (distances around 1.5 m in Fig. 6b and so, small differences in measurement probe location point (as much in distance as in orientation), can cause important errors. Slight deviations of measurement probe location at point 6 (front side) however results in a much smaller errors.




a) Horizontal direction.

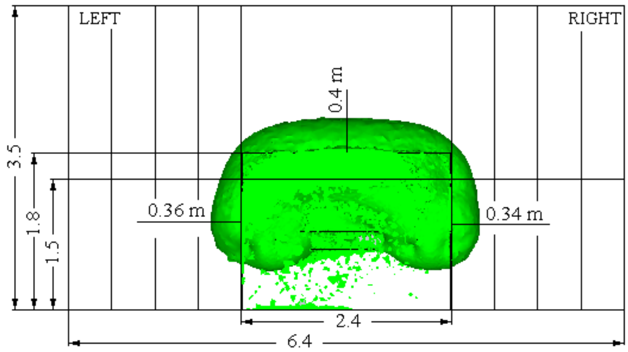



b) Vertical direction.

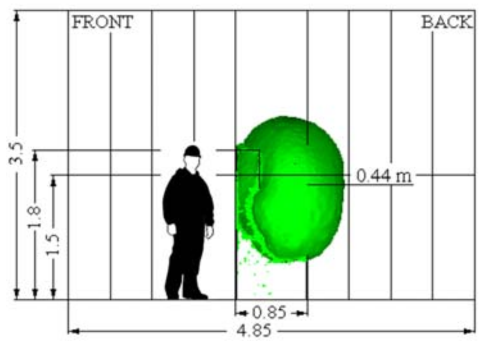
Fig. 6. Magnetic flux density versus distance.

## B. Magnetic exposure

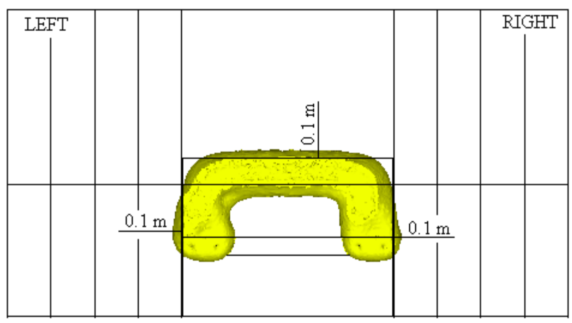
Figure 7 shows the volume of magnetic flux density (resultant component) around the analysed switchgears that is equal or higher than the mentioned limit of 100 µT and 500 µT, and the maximum distance between the switchgears and the boundary of the volume over different directions.



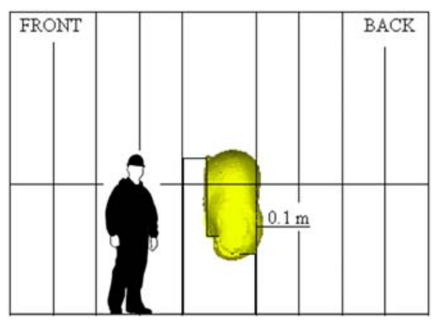

a) Front view, 100 µT.




b) Right view, 100 µT.




c) Front view, 500 µT.




c) Right view, 500 µT.

Fig. 7. Magnetic emissivity over:100 µT and 500 µT.

It can be noticed that:

- maximum distance between the switchgear metallic enclosures and magnetic emissivity volume over 100 μT is 0.36, 0.4, 0.34 and 0.44 m in right, left, upper, and back sides, respectively, while in the front side (switchgear operation) remains inside switchgears;
- magnetic emissivity volume over 500 μT is almost totally inside switchgears (area with SF6 isolation);
- magnetic field density levels are always higher at switchgear back side (not accessible to operators) than at front side (switchgear operation), where magnetic field values never reach 100 μT.

It is important to mention that magnetic emissivity charts shown above were developed for five switchgears in open air, without taking into account possible interference with other surrounding equipment. Those switchgears are designed for indoor installation and in general they are installed in prefabricated or built transformer substations, reason for which a real installation should be studied as a whole (low voltage bridge, transformer, switchgears, low voltage board, etc.). The concrete/brick enclosure keeps general public far away from the 100 μT exposure limit.

## 6. Conclusions

A methodology, using FE technique, for the switchgear magnetic field assessment has been developed in this paper and the results are compared with those obtained in the laboratory tests. Both, simulation and laboratory tests, definitely show that MF density levels at switchgear front side (accessible to operators) are lower than those recommended for workers and general public by EU Council.

To obtain accurate results it is important to observe the following rules: 1) users must possess enough technical knowledge both about the physical phenomenon and the application of the FE method as a means of MF simulation; 2) the testing probe has to be characterized, in terms of performance and data acquisition accuracy; 3) it is of the highest importance, for validation of FE simulation results by means of magnetic flux density measurements in laboratory tests, clear definition and careful and accurate positioning of the points, and 4) use of a measurement device with a testing probe capable of directly measure the magnetic flux density resultant component is very commendable.

## References

[1] 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 Physics, vol. 74, no 4, pp. 494-522, April 1998.

[2] --------, Recomendación del consejo Europeo sobre los límites de exposición del público a campos electromagnéticos (0 Hz a 300 GHz) 1999/519/CE, July 1999.

[3] Ministerio de Sanidad y Consumo, “Campos electromagnéticos y salud pública”, Madrid, 2001.

[4] B. W. Jaekel, “General description and assessment concept for magnetic field distributions caused by switchgear installations”, *IEEE Trans. Power Delivery*, Vol.. 22, No. 1, pp. 167-177, January 2007.

[5] T. R. O. Almeida, A. Paulo Coimbra, C. F. R. Lemos Antunes, “Low frequency electromagnetic fields in power transformer rooms”, 9th Spanish-Portuguese Congress on Electrical Engineering, in Proc. 9CHLIE 2005, Marbella, Spain.

[6] International Electrotechnical Commission, “IEC/TR 62271-208: High-voltage switchgear and controlgear – Part 208: Methods to quantify the steady state, power-frequency electromagnetic fields generated by HV switchgear assemblies and HV/LV prefabricated substations”, October 2009.

[7] J. Izagirre, L. Del Rio, I. Gilbert, J. E. Rodriguez-Seco, J. A. Güemes, A . M. Iraolagoitia, “Validation of a simulation tool for evaluation of magnetic fields generated by transformer substations according to IEC/TR 62271-208”, in Proc. 2nd International Conference on Extremely Low Frequency Electric and Magnetic Fields, in Proc. EMF-ELF 2011 (cigré), Paris, France.

[8] www.ormazabal.com.