USEOF MAGNETIC FIELD CALCULATION TOOLS TO DESIGN MV / LVSUBSTATIONS

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ABSTRACT

Medium Voltage (MV) to Low Voltage (LV) Substations are one of the last links in the distribution process of Electric Power. Associated with these is the generation of magnetic field. These have generated great concern in the population due to its possible link to health effects in humans, so it is necessary to know what are the levels generated by existing and new facilities, considering different constructive topologies.
To achieve the objective, magnetic field calculations are performed using 3D simulation tools, allowing to reproduce the layout of ground level substations, knowing the magnetic field values for different loading conditions and considering balanced and unbalanced load conditions, with current in neutral conductors.
In 2013 measurement campaigns of Magnetic Field on substations were performed, also loads were surveyed.
The results of the calculation of magnetic field generated by ground level substations, considering different topologies used in Argentina are presented in this paper.
In order to validate the results, comparisons between measured and calculated values are performed.
Generated levels are studied for different cases.
Obtained magnetic fields values are compared with limits of Argentinean regulation [1] and recommended references values by international organizations such as ICNIRP (International Commission on Non-Ionizing Radiation Protection) [2] and IEEE (Institute of Electrical and Electronics Engineers) [3].

INTRODUCTION

There are substations of different characteristics, such as aerial, underground or at ground level, the latter in many circumstances are adjacent to private property or public roads. In Argentina most works on voltages from 13.2 to 0.4 kV. The installed power depends on demand, typically found transformers 315, 500, 800 and 1000 kVA. In many cases more than one in a substation.
In this paper aims to analyze the levels of magnetic field generated by a typical substation with a transformer and a fixed number of low voltage feeders.
Different loading conditions are considered, with balanced and unbalanced loads.
In Fig. 1, the line diagram of a typical scheme is presented. This substation are linked with another two in MV (1 and 2), MV board, a feeder to the transformer (I_{MT}), LV feeders that link the transformer with the LV distribution board (I_{BT}) and LV feeders, in this case 8.

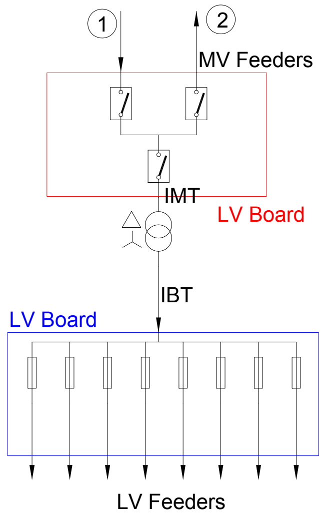

Fig. 1. MV/LV Substation scheme

CONSTRUCTION DETAILS

The substations will vary according to how they are made internally. There are different types of MV boards. The link between the MV boards and the transformer, in MV, in most cases is made with cables, these can be laid at ground level or below of the ground level.
The next step connects the transformer with the LV board. This can be done by means of bars, lying on tray cables, lying at floor level or below ground level cables.
Fig. 2 shows a layout in which the elements described are identified.

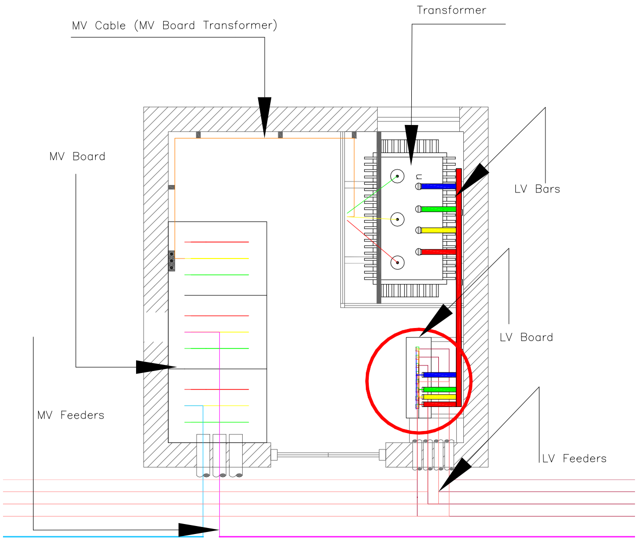

Fig. 2. Layout

The LV distribution board is then placed, it can be conventional or compact, the difference is that the compact has smaller spacing between the bars and the spacing between the feeders is lower. The last stage is LV feeders.
This paper considers a model of typical commercially available MV board, MV three-phase cable, lying at ground level to the power transformer.
For the link between the transformer and the LV board are considered bars arranged on the wall of the substation.
Two types of LV boards, with different distances between bars and LV feeders, are considered. In Fig 3 (Conventional) and Fig. 4 (Compact) is possible to see images of the considered LV boards.

Fig. 3. Conventional LV board.

The main difference is the spacing between the bars and between the LV feeders. The conventional board have a greater distance between the feeders.


Fig. 4. Compact LV board.

Another difference is that the connection from the transformer in the conventional case is carried out in the same way side, while in the compact type is performed at the top.
MV and LV feeders, is made with underground cables, considering the minimum depth established in the Argentinean regulations [4].Was considered the minimum separation between cables of the same voltage and between cables of different voltages.
MV feeders were considered with three phase cables, whose phase separation is 2 cm.
LV feeders were considered with four phase cables, whose phase separation is 1 cm.
In Table I is possible to see the distances according to the Res. ENRE 129/2009 [4].

Table I. Distance between feeders, Res ENRE 129/2009

Distance	**D_{min} [m]**
Between LV feeders and the ground surface	0,7
Between LV feeders	0,15
Between LV and MV feeders	0,2
Between MV feeders and the ground surface	1
Between MV feeders	0,15

MAGNETIC FIELD

To evaluate the magnetic field generated by this type of installation is necessary to consider all possible sources, so it is essential to know the location of each feeders and the current.
Usually LV loads are unbalanced, this causes currents for the neutral conductor, the influence on the values of the magnetic field depends also of the magnitude and phase angle of this current.
Measurement procedures of magnetic fields produced by lines and industrial facilities often are described in the IEEE 644-1994 [5] and IEC 61786: 1998 [6].
According to these standards, the indication of a three axes meter, called resulting field (B_R), is defined according to equation (1).

$$B_R = \sqrt{B_X^2 + B_Y^2 + B_Z^2} \qquad (1)$$

Where should get the three spatial components that define the field: B_X, B_Y and B_Z.
For calculations were performed three-dimensional models and field values on each axis were calculated, with these values proceeded to obtain the resultant field as indicated in (1).
Images were generated in which the values of magnetic field overlap to the substation layout. Field values are represented by colours, representing different values of magnetic field (isolines).

CASES

In measurement campaigns carried out in 2013 the substations loads were measured at the time of measurement of magnetic fields, this information was incorporated into a database and then some cases were selected for calculations of magnetic fields.
The currents were measured in LV side of transformer, so it was necessary to estimate the MV current.
It was also considered that the LV current is evenly distributed among all LV feeders. In Table II is presented

the considered balanced (B) and unbalanced (U) currents.

Table II. Considered currents.

Case	Currents [A]						
	I_{BTr}	I_{BTs}	I_{BTt}	I_{BTn}	I_{MTR}	I_{MTS}	I_{MTT}
B	490 e^{j-30}	490 e^{j-150}	490 e^{j90}	0 e^{j0}	14,9 e^{j0}	14,9 e^{j-120}	14,9 e^{j120}
U	500 e^{j0}	490 e^{j-125}	555 e^{j120}	100 e^{j126}	14,6 e^{j27}	14,7 e^{j-90}	15,2 e^{j148}

Table III presents the cases considered, detailing the type of board considered, the load and the neutral current.

Table III. Cases considered.

Cases	LV Board	Load	$I_{neutral}$ [A]
1	Conventional	Balanced	0
2		Unbalanced	100
3	Compact	Balanced	0
4		Unbalanced	100

RESULTS

The results are presented by different types of graphics in which the magnetic field values obtained for each case.
The calculations were performed on the perimeter and 1 m above the ground.
The graphs presented are:

- Isolines of magnetic field.
- Longitudinal profiles of magnetic field.

The isolines correspond to points of equal value of magnetic field.
In Fig. 6 and 7 the results obtained for Case 1 and 2, respectively, are showed.

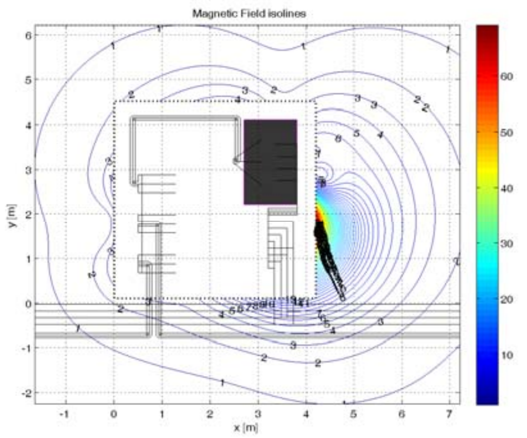

Fig. 6. B isolines, Case 1

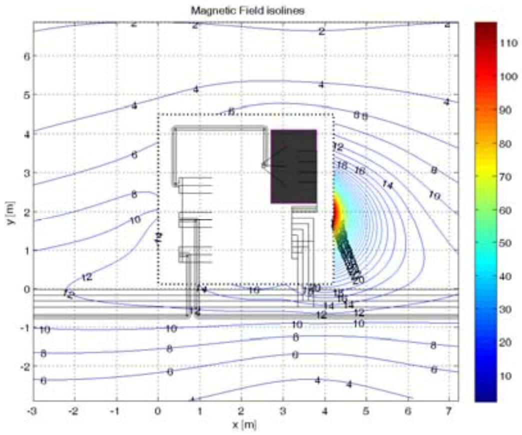

Fig. 7. B isolines, Case 2

In Fig. 8 and 9 the results obtained for Case 3 and 4, respectively, are presented.

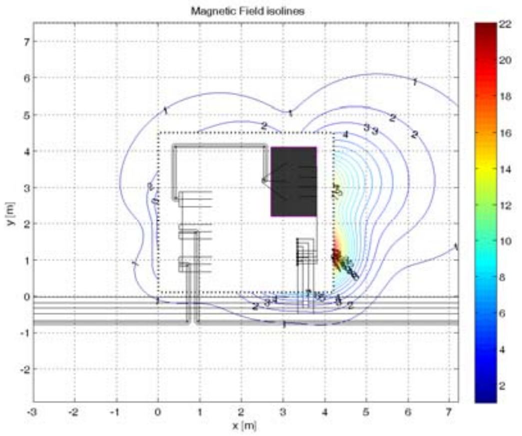

Fig. 8. B isolines, Case 3

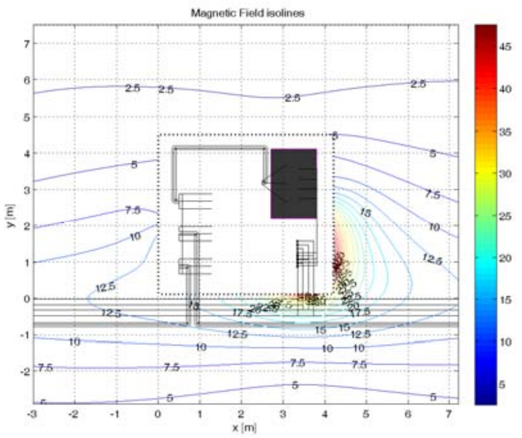

Fig. 9. B isolines, Case 4

MEASUREMENTS

To validate the implemented models a comparison between calculations and measurements were performed.
Measurements were made on one substation whose constructive characteristics are similar to those of Case 3. The comparison is performed only on the wall back to LV board and transformer.
The comparison is shown in Fig. 10 is performed by a profile B, route 1 m of the soil and 1 m of the substation wall. Solid line calculated values are represented with points represent the measured values. 25 µT limit indicated by [1] are also indicated with dotted line.

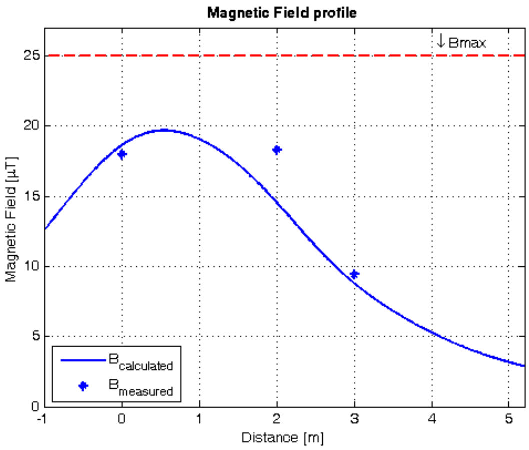

Fig. 10. Perfiles de B, sin lazo y Caso 4, para diferentes las secciones.

Comparing the results obtained in the simulation and the measurement, it can be said that the differences are acceptable. The calculation model is a good approximation of the values produced by existing installations.
At one point a greater difference between measured and calculated values is appreciated. This is due to the existence of magnetic field sources external to the substation, not included in the model.

RESULTS ANALISIS

Field values are calculated in the outdoor substations, since this is where the applied Res . SE 77/1998 [1].
Analyzing the results can be different conclusions. With the contour can analyze the location of the points of greatest value of magnetic field and the area where these values are reached.
The highest magnetic field values were generated in the surrounding of the LV board and LV bars.
When considering balanced currents, smaller field values are obtained.
When considering a neutral current of 100 A, higher field values are obtained. This is because there are additional feeders with current.
It is further noted that the compact board generally yields better results than conventional, as the distances between the conductors are lower.

The maximum values for the analyzed cases are presented in Table IV.

Table IV. Maximum values of B

Case	Bmáx. [µT]			
	Calc.	Res. SE 77	ICNIRP	IEEE
1	69	25	200	904
2	115			
3	22,5			
4	48			

Analyzing Table IV is observed that three cases exceed 25 µT. So it is necessary to consider some mitigation alternative.

MITIGATION

Field values are calculated in the outdoor substations, since this is where the applied Res. SE 77/1998 [1].
Taking advantage of the tool available, was decided to study what would be the distance that should settle the boundary of the substation, so that the magnetic field values conform to the regulations.
Analyzing Fig. 6 to 9, the areas where 25 µT exceed are identified.
For cases 1 and 2 this value is exceeded only in the back of LV board.
For Case 4, this also occurs on the side LV board.
Therefore it was decided to locate the boundary of substation at 1 m from the original, on the back of the LV board.
To cover the situation of Case 4 was shifted 0.5 m limit to the side of LV board. The results are presented in Fig. 11 to 14.

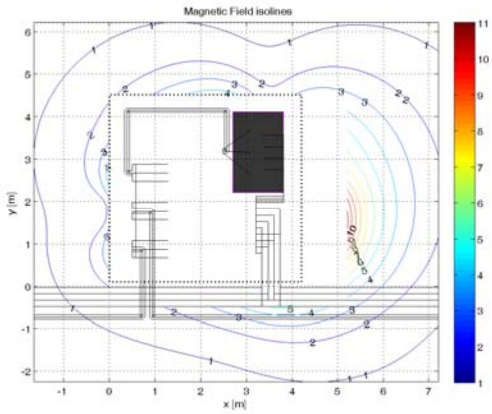

Fig. 11. B isolines, Case 1.

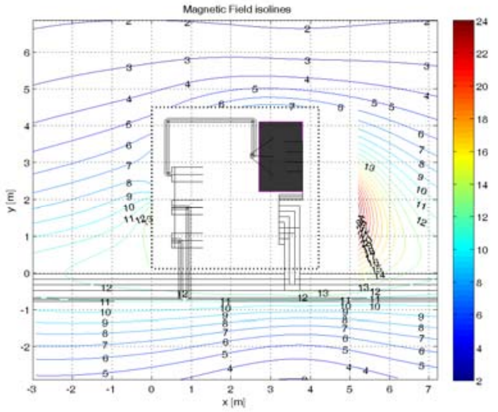

Fig. 12. B isolines, Case 2.

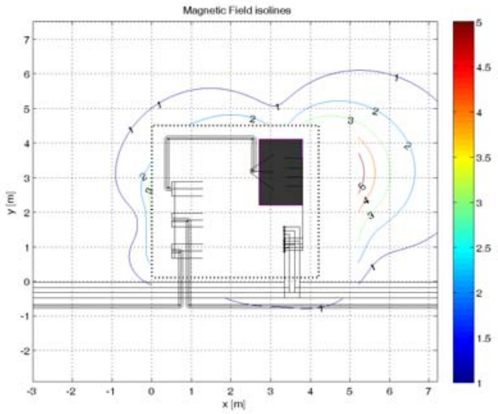

Fig. 13. B isolines, Case 3.

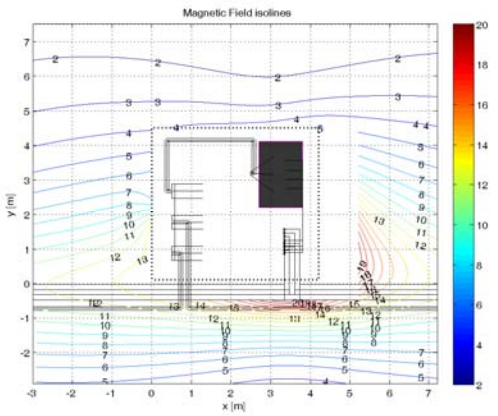

Fig. 14. B isolines, Case 4.

In Table V the new maximum values and comparison with the references are presented.

Table V. Maximum values of B

Case	Bmáx. [µT]			
	Calc.	Res. SE 77	ICNIRP	IEEE
1	11	25	200	904
2	24			
3	5			
4	20			

CONCLUSIONS

Analyzing the results, it can be said that the implemented models allow calculations who represent a good approximation to the values generated by the existing facilities.

This is evident when a comparison is made with measurements.

The calculation tools allow us to know the impact of installing new substations or modifying existing ones. Considering different designs influence on magnetic field levels.

When considering new facilities, it is possible to decide what is the best solution for each case, from the point of view of the distribution of magnetic field.

In addition, is possible to check if the values exceed the magnetic field limit, indicated by current regulations. To which one must consider the different load cases.

Considering an existing installation, is possible to register the load curve of a substation, recording values of phase and neutral LV current, in module and phase. From this estimate what the magnetic field levels that are generated, for a full load or greater neutral current value.

REFERENCES

[1] Resolución SE 77/98, Secretaría de Energía de la Nación (Argentina). Boletín Oficial N° 28.859 1ª Sección.

[2] "Guidelines for Limiting Exposure to Time-Varying Electric and Magnetic Fields (1 Hz to 100 KHz)". ICNIRP 2010. Health Physics Society 15 June 2010, 818-836.

[3] IEEE StdC95.6-2002: IEEE Standard for Safety Levels with Respect to Human Exposure to Electromagnetic Fields, 0-3 kHz.

[4] Resolución ENRE 0129/2009. Boletín Oficial n° 31.598, jueves 19 de febrero de 2009, p. 49. Condiciones Mínimas de Seguridad para Líneas Subterráneas Exteriores de Energía y Telecomunicaciones.

[5] IEEE Std. 644TM-1994 (R2008), "IEEE Standard Procedures for Measurement of Power Frequency Electric and Magnetic Fields From AC Power Lines".