Turk J Elec Eng & Comp Sci, Vol.17, No.3, 2009, © TÜBİTAK
doi:10.3906/elk-0908-182

Modeling and calculation of electromagnetic field in the surroundings of a large power transformer

Leonardo ŠTRAC[1], Franjo KELEMEN[2], Damir ŽARKO[3]
[1] *Koncar Power Transformers Ltd., Research and Development Department*
Josipa Mokrovica 6, 10090 Zagreb-CROATIA
e-mail: leonardo.strac@siemens.com
[2] *Koncar Power Transformers Ltd., Research and Development Department*
Josipa Mokrovica 6, 10090 Zagreb-CROATIA
e-mail: franjo.kelemen@siemens.com
[3] *University of Zagreb, Faculty of Electrical Engineering and Computing,*
Department of Electrical Machines, Drives and Automation Unska 3, 10000 Zagreb-CROATIA
e-mail: damir.zarko@fer.hr

Abstract

The presented study compares measured and calculated electromagnetic field quantities in the surroundings of a large power transformer with the aim to avoid the necessity of measuring the field on subsequent units and use a computer model instead. The influences of various objects located in the vicinity of the transformer during measurement are also analyzed and are taken into account in a computer model.

Key Words: *Large power transformer, electromagnetic field, finite element method.*

1. Introduction

Large power transformers produce electric and magnetic fields that can affect human health and have influence on the environment. Therefore, most countries have legal regulations regarding peak values of electromagnetic field to which people in residential areas, offices or industrial plants may be exposed [1–3]. Although switchyards are usually placed on isolated locations, customers who purchase power transformers often require technical documentation and certificate about electromagnetic field emission of a transformer.

A background of this project was a special customer request for one transformer. The transformer was to be placed in a switchyard near an office building. The customer requested peak electric field less than 5 kV/m and peak magnetic field less than 100 μT at a distance of 30 m from the transformer (tank). The basic transformer ratings are: 3-phase transformer, 220 MVA, 240 kV, 50 Hz. Due to lack of experience regarding similar problems, the most reasonable course of action was to find a similar transformer (by the criteria of nominal power, nominal voltage level and short circuit voltage) in the current factory production and make initial tests. A similar transformer with basic ratings 3-phase transformer, 250 MVA, 300 kV, 50 Hz was chosen.

Since every additional measurement in tight time schedule of the high-voltage laboratory requires overtime work, sometimes even a night shift, and this type of measurement requires special equipment or outsourced measurement, this paper explores the possibility of determining electric and magnetic field in the surroundings of a transformer using only a computer model in order to avoid expensive measurements. The results obtained from magnetic and electric field measurements carried out in the high-voltage laboratory in Končar Power Transformers are compared to the results of computer simulations. The transformer and the auxiliary equipment in the laboratory are shown in Figures 1 to 3.

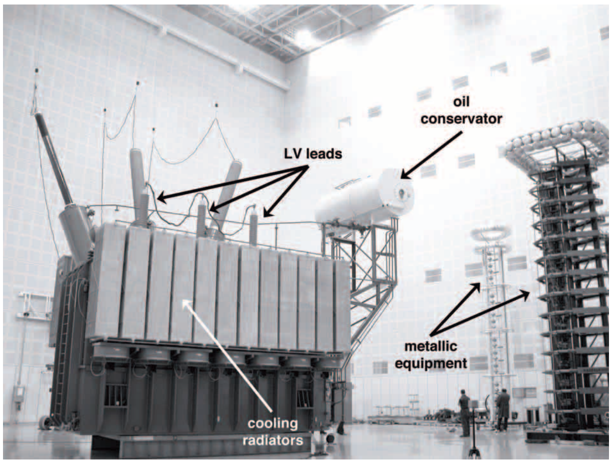

Figure 1. Picture taken in the high voltage laboratory of Končar Power Transformers, transformer 250 MVA, 300 kV.

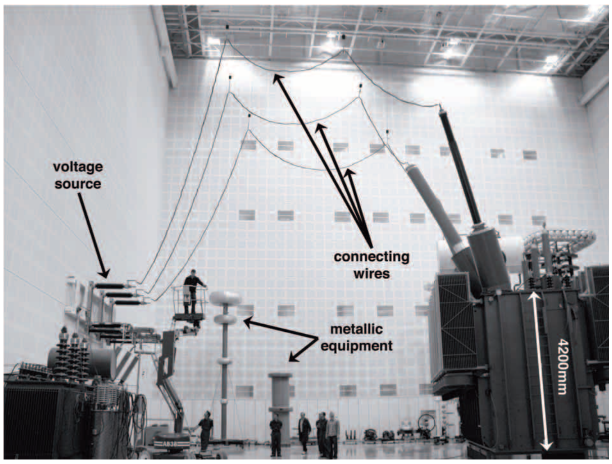

Figure 2. Side view of the 250 MVA, 300 kV transformer with the wires connecting the source to the transformer.

The computer model had to be defined very carefully in order to encompass all the influences that various objects surrounding the transformer might have had on the electromagnetic field during measurement. The electric field distribution is influenced by any sort of conductive material and it is assumed that large metallic objects behave as shields for the field [4]. The magnetic field is mostly influenced by materials with high relative permeability [4], particularly steel which can be found in concrete reinforcement, small electric machines and different sorts of steel plates which are often hidden from plane sight and therefore have unexpected influence.

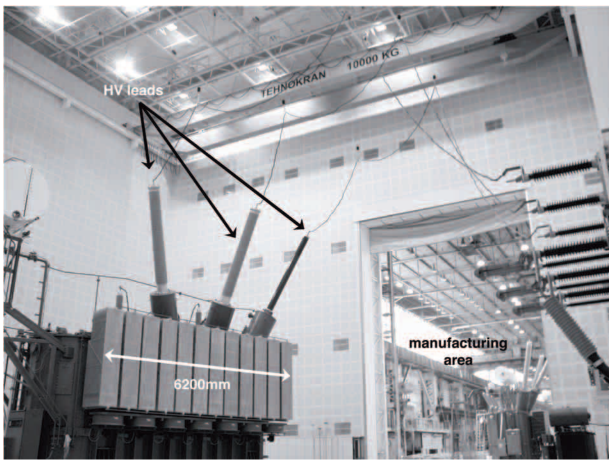

Figure 3. Another view of the high voltage laboratory.

The measurement is managed by Končar Institute for Electrical Engineering, Zagreb, with a PMM EHP-50C Electric and Magnetic Field Analyzer and a PMM 8053 Field Meter. Technical specifications of EHP-50C Analyzer are: frequency range 5 Hz – 100 kHz for electric and magnetic field, sensitivity 0.01 V/m, 1 nT, absolute error ± 0.5 dB (@ 50 Hz and 1 kV/m) (@ 50 Hz and 0.1 mT), electric and magnetic field rejection >20 dB. Measured values are average of x,y, and z components for the frequency of 50 Hz. A wooden tripod was used to hold a probe in front of the transformer. The electromagnetic field is calculated using 3D finite element software Ansoft Maxwell, a standard FEM software used in Končar Power Transformers. Magnitude of field values were calculated using the equation $F = \sqrt{F_x^2 + F_y^2 + F_z^2}$.

2. Model of the 250 MVA, 300 kV transformer

All finite-element models in this paper are made using Ansoft Maxwell commercial software. Magnetic field was calculated in magnetostatic mode. Since there are no induced currents in this type of calculation, the conductivity of all materials is set to zero (except for copper wires). The material for the surrounding box of the transformer model is vacuum. The parts made of transformer steel (core and tank shields) have hundred times higher relative permeability than those made of plain steel (tank, clamping plates and consoles). The current sources are used in the model and copper conductors are simulated to be stranded in order to ensure uniformly distributed current across the conductor's cross section. The boundary conditions at the end region are set as Neumann boundaries. All parts inside the tank were modeled as simple as possible in order to reduce the computational time without significantly affecting the overall field solution. The model mesh contains about one million tetrahedrons in the final mesh refinement, and it takes about 12 hours of computing time on a multi-core workstation to complete the calculation.

The model for calculating electric field is very similar. In this case voltage sources were used for the transformer leads.

The basic model is established for the autotransformer of nominal power of 250 MVA and a nominal voltage of 300 kV. All the calculations are carried out for the frequency of 50 Hz because it is the transformer's nominal frequency. Since this is not a special purpose transformer (rectifying, HVDC, etc.), it was not necessary to calculate and measure electromagnetic field at higher frequencies. This computer model is valid for the frequency of 60 Hz as well. The initial assumption was that it should be enough to model an empty tank and short circuited low-voltage (LV) and high-voltage (HV) leads excited with the nominal currents to calculate the distribution of magnetic field in the space surrounding the transformer. However, results of the calculation differed from the measured values more than 20 dB, and the conclusion was that the model was not detailed enough. For that reason there were numerous improvements that had to be added to the model, like oil conservator, cooling radiators, wires connecting the source on the laboratory wall to the leads, laboratory's Faraday cage and, finally, the transformer in the model was moved to the exact position and oriented adequately relative to the laboratory walls. After these improvements have been made, the calculated field distribution near the transformer was significantly closer to the measured one (up to the 10 dB difference), but the field 5 to 10 meters from the transformer was too small (10 to 19 dB difference for the HV and LV side).

As it can be seen in the Table 4, in the column Measured/Leads (calculated using equation 20 Log($B_{measured} / B_{calc\_Leads}$), the difference between the measured values and the values calculated for the model with leads is increasing rapidly with distance. At this point it was obvious that the field originating from the active part of the transformer cannot be ignored although the transformer tank is an excellent EM shield. In the end, three supplemental models have been derived from the basic model: the first to calculate stray magnetic field of the windings, the second to calculate magnetic field caused by the leads stray flux and the third to calculate electric field caused by the leads.

The magnetic field calculation is separated in two different tasks because it would be very difficult to make a detailed model incorporating both helix type winding and leads. The helix-shaped windings on all phases, including both high-voltage and middle-voltage windings, would form an extremely complex geometry. Hence, the finite element mesh for such a model would be too demanding for the available computer hardware. Moreover, the solution of magnetic field in the air surrounding the transformer would probably contain large errors because the software would have to deal predominantly with complex mesh inside the transformer. For that reason the first model has cylinder-shaped windings, closed tank without openings and does not have leads (Figures 4 to 5), while the second model does not incorporate windings, but only the short circuited leads (Figure 6).

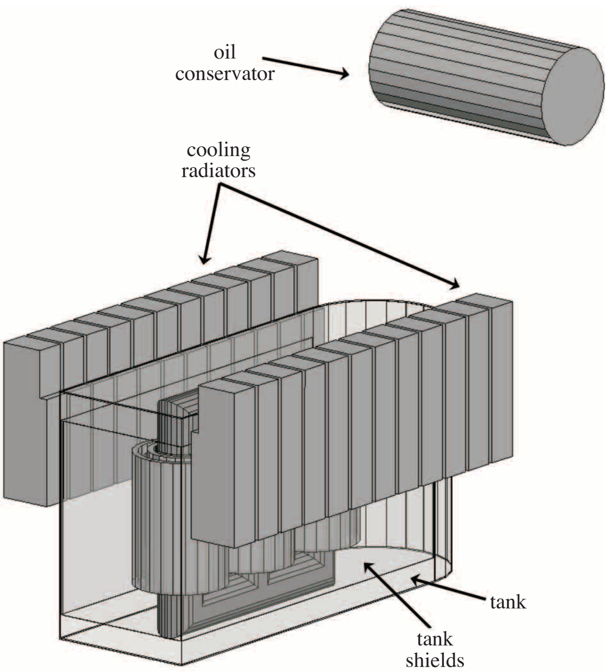

Figure 4. The model with windings for magnetic field calculation, 250 MVA, 300 kV transformer.

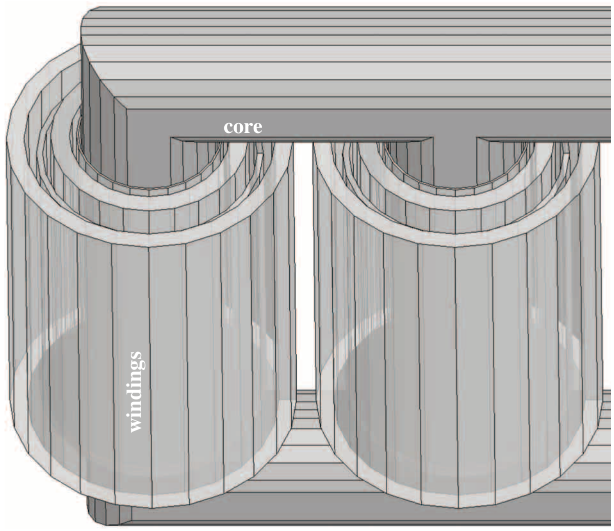

Figure 5. Detail of the active part of the 250 MVA, 300 kV transformer.

The model for calculating electric field (Figure 7) is similar to the model without windings for magnetic field calculation. The main difference is that the leads are not short circuited. The influence of windings is neglected because the windings are well shielded by the earthed tank.

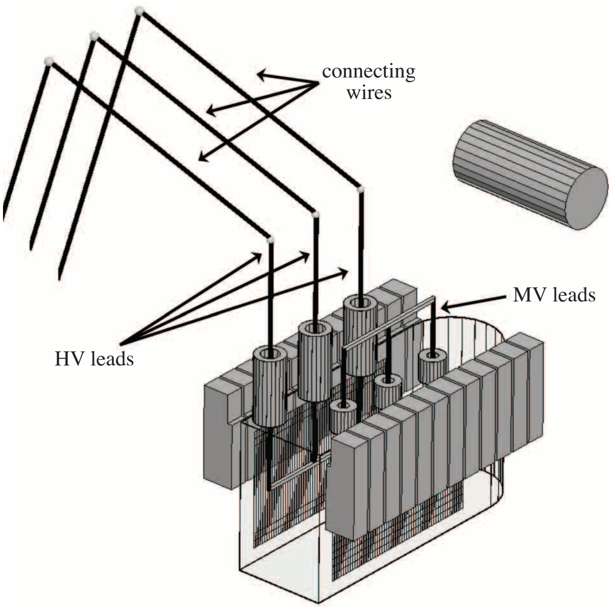

Figure 6. The model with leads for magnetic field calculation, 250 MVA, 300 kV transformer.

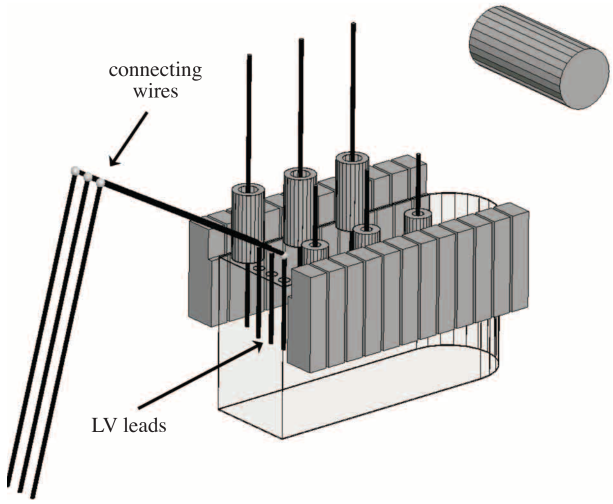

Figure 7. The model with leads for electric field calculation, 250 MVA, 300 kV transformer.

Since the laboratory is not an empty space and the transformer is quite a complex device, various modifications have to be made on the computer model in order to better describe the physical reality [5]. The copper lines that connect the transformer to the current source are particularly important. Both the electric and the magnetic model (with leads) have to include copper lines which connect the leads and the source because of their great influence on the field distribution throughout the space. The oil conservator is included in all three models, but has the greatest impact on electric field calculation. The similar situation is with tank shields, which are made from transformer steel sheets and are located on the inner tank wall surface. They have the greatest influence on magnetic field, but they are present in all three models. The influence of the iron Faraday cage that is built in the high voltage laboratory on both electric and magnetic field has been considerable, so it had to be taken into account. The Faraday cage is modeled as a thin empty iron box that surrounds the entire model at the appropriate distance.

All the calculations were performed using Ansoft Maxwell finite element software in magnetostatic and electrostatic calculation mode.

All the field measurements were carried out on the high voltage (HV) side, middle voltage (MV) side, low voltage (LV) side and oil conservator (CS) side of the transformer (Figure 8). On each side the measurements were carried out 1, 2, 4, 6, 8 and 10 meters away from the tank respectively (where that was possible) and at a height of 1.25 meters from the bottom of the transformer.

Table 1 represents peak ampere-turns for high voltage (HV), middle voltage (MV) and regulation winding used in the model for magnetic field calculation with the winding and without leads. These are the ampere-turns for the neutral regulation position. Table 2 represents the peak current in the high voltage (HV), middle voltage (MV) and low voltage (LV) leads used in the model for magnetic field calculation with the leads and without winding. Table 3 gives the values of peak voltages applied to the high voltage (HV), middle voltage (MV) and low voltage (LV) leads used in the model for electric field calculation.

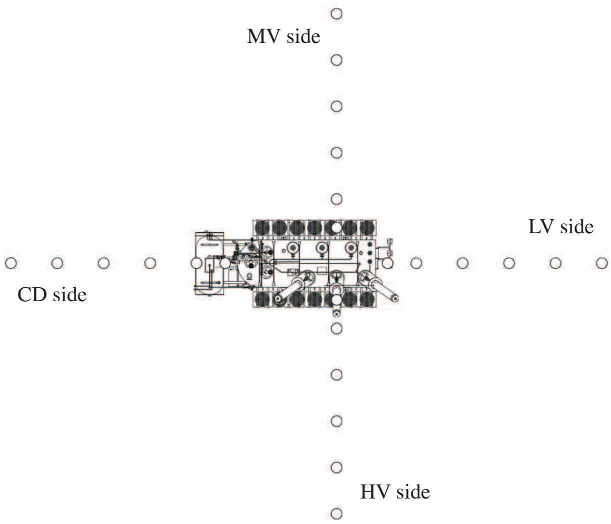

Figure 8. Top view of the transformer with marked measurement points, 250 MVA, 300 kV transformer.

Table 1. Peak ampere-turn values in the windings for the magnetic field model with windings, 250 MVA, 300 kV transformer.

	Peak ampere-turns		
	HV	MV	regulation
Phase 1	182500	-202000	19500
Phase 2	-365000	404000	-39000
Phase 3	182500	-202000	19500

Table 2. Values of peak current in the leads for the magnetic field model with leads, 250 MVA, 300 kV transformer.

	Peak current [A]		
	HV	MV	LV
Phase 1	371	773	0
Phase 2	-742	-1546	0
Phase 3	371	773	0

Table 3. Values of peak voltage in the leads for the electric field model with leads, 250 MVA, 300 kV transformer.

	Peak voltage [V]		
	HV	MV	LV
Phase 1	336804	161666	-15556
Phase 2	0	0	31112
Phase 3	-336804	-161666	-15556

3. Results for the 250 MVA, 300 kV transformer

3.1. Magnetic field

The calculation of the magnetic field was carried out in two parts. In the first part, only the field from the windings, and in the second part only the field from the leads was calculated at each measurement point. Later, the two values were added.

From Table 4 and Figures 9 to 10 it can be noticed that the differences between calculated and measured values are not small in an absolute sense, but the calculated magnetic field in the model behaves qualitatively as the measured one. It is also evident that the measured magnetic field does not diminish as fast as it could be expected, and this may be caused by conductors beneath the floor in the laboratory. Additionally, the point HV_08 has unusually high flux density because of the influence of the current source near the laboratory wall. Both effects could not have been reconstructed in the model. As the columns *Measured/Leads* and *Measured/Total* in the Table 4 show, introducing the model of the active part was justified since the difference between measured and calculated values is reduced.

3.2. B. Electric field

The calculation of the electric field was more straightforward than the calculation of the magnetic field. The influence of the winding and wires inside the tank was neglected, so only the field from the leads was taken into account.

Table 4. Peak values of flux density in the surroundings of the 250 MVA, 300 kV transformer.

distance	point	Windings	Leads	Total	Measured	Me./Le.	Me./Tot.
[m]		Br[uT]	Br[uT]	Br[uT]	Bm[uT]	[dB]	[dB]
1	HV_01	4,64	7,95	12,59	14,52	5,23	1,24
2	HV_02	2,90	5,54	8,44	9,76	4,92	1,26
4	HV_04	1,60	2,99	4,58	6,08	6,18	2,45
6	HV_06	1,61	1,59	3,20	5,57	10,90	4,81
8	HV_08	0,38	0,79	1,17	7,30	19,28	15,88
1	LV_01	1,25	10,16	11,41	8,71	-1,34	-2,35
2	LV_02	1,06	5,57	6,63	7,45	2,53	1,01
4	LV_04	0,58	2,66	3,24	5,33	6,04	4,33
6	LV_06	0,45	1,19	1,64	3,78	10,03	7,25
8	LV_08	0,25	0,75	1,00	2,81	11,44	8,98
10	LV_10	0,16	0,42	0,58	2,03	13,64	10,84
1	MV_01	5,32	8,76	14,09	25,32	9,22	5,09
2	MV_02	3,37	6,66	10,03	17,08	8,18	4,62
4	MV_04	0,98	3,04	4,02	8,2	8,63	6,19
6	MV_06	0,14	1,38	1,52	4,62	10,48	9,64
8	MV_08	0,11	1,01	1,12	2,66	8,44	7,53
10	MV_10	0,09	0,69	0,78	1,56	7,12	6,07
1	CZ_01	1,33	7,18	8,51	5,44	-2,41	-3,89
2	CZ_02	0,80	3,88	4,68	4,5	1,29	-0,33
4	CZ_04	0,44	2,50	2,94	3,19	2,11	0,70
6	CZ_06	0,24	1,29	1,54	2,25	4,81	3,31
8	CZ_08	0,09	0,58	0,67	1,63	9,02	7,76

The distribution and the values of the electric field in the model, shown in Table 5 and Figures 11 to 12, are in a reasonably good agreement with measurements (difference is up to 12 dB with tendency of decreasing with distance), with the exception of the LV side. The reason why the measured electric field on the LV side is much smaller than calculated in the model remains unclear, but the reason probably lies in different layout of the copper lines in the model and the actual transformer.

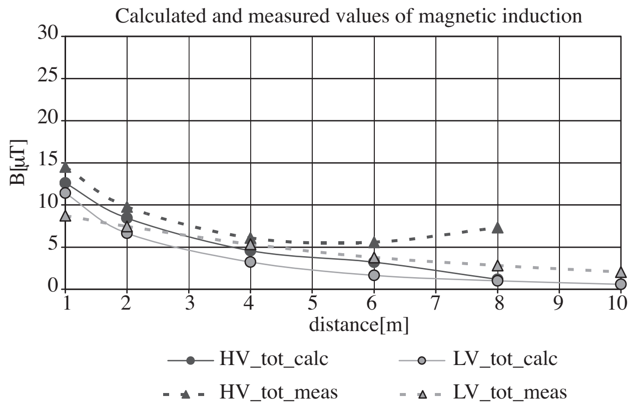

Figure 9. Calculated and measured values of flux density in the surroundings of the 250 MVA, 300 kV transformer, part 1.

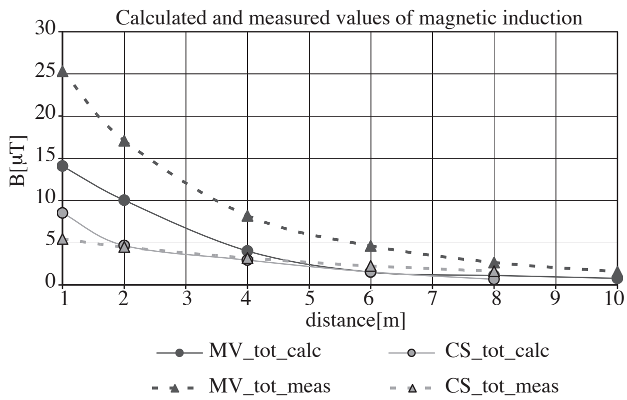

Figure 10. Calculated and measured values of flux density in the surroundings of the 250 MVA, 300 kV transformer, part 2.

Table 5. Peak values of electric field outside the 250 MVA, 300 kV transformer.

distance	point	Leads	Measured	Me./Le.
[m]		Er [V/m]	Em [V/m]	[dB]
1	HV_01	71	96	2,54
2	HV_02	107	177	4,37
4	HV_04	214	273	2,14
6	HV_06	170	253	3,44
8	HV_08	111	180	4,19
10	HV_10	57	111	5,80
1	LV_01	852	276	-9,78
2	LV_02	960	331	-9,26
4	LV_04	1054	301	-10,87
6	LV_06	792	241	-10,33
8	LV_08	443	350	-2,05
1	MV_01	32	22	-3,31
2	MV_02	120	37	-10,19
4	MV_04	120	61	-5,90
6	MV_06	99	61	-4,29
8	MV_08	45	47	0,39
10	MV_10	24	35	3,39
1	CZ_01	200	55	-11,26
2	CZ_02	228	60	-11,65
4	CZ_04	209	71	-9,36
6	CZ_06	161	62	-8,28
8	CZ_08	121	45	-8,60

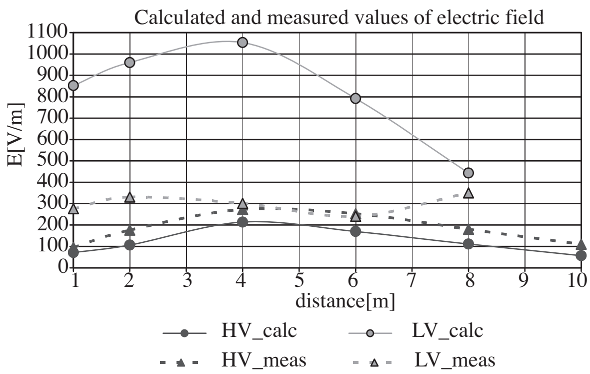

Figure 11. Calculated and measured values of electric field outside of 250 MVA, 300 kV transformer, part 1.

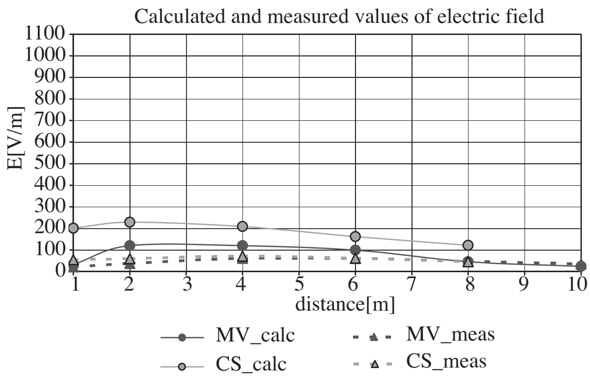

Figure 12. Calculated and measured values of electric field outside of 250 MVA, 300 kV transformer, part 2.

4. Results for the 220 MVA, 240 KV transformer

After acquiring experience with the model of the 250 MVA, 300 kV transformer, the transformer for which the customer originally requested specific electromagnetic field emission was modeled in the same manner. Although these two transformers are considered similar from the manufacturing point of view, they differ in many ways that can impact the distribution of electromagnetic field: nominal power and voltage, short circuit voltage, layout of the winding, position of the leads, number, position and size of the cooling radiators, size of the oil conservator etc. (Figure 13).

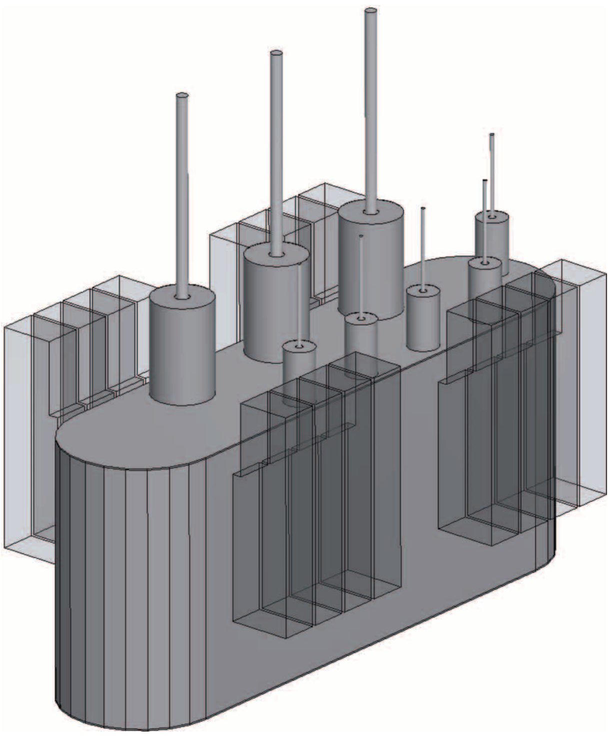

Figure 13. The model with leads for electric field calculation, 220 MVA, 240 kV transformer.

Since the layout of the switchyard where that transformer was going to be placed was unknown, it was decided that the computer model should include only the transformer itself. The customer requested peak electric field less than 5 kV/m and peak magnetic field less than 100 μT at a distance of 30 m from the transformer (tank), so the calculation was extended to the 30 m range. The key point here is that this range is beyond the laboratory space and cannot be measured in the available laboratory. Figure 14 shows the calculation points on high voltage (HV), low voltage (LV), left (L) and right (R) side of the transformer at 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 15, 20, 25 and 30 meters away from the transformer tank.

Table 6 represents peak ampere-turns for high voltage (HV), middle voltage (MV) and regulation winding used in the model for magnetic field calculation with the winding and without leads. These are the ampere-turns for the neutral regulation position. Table 7 represents the peak current in the high voltage (HV), middle voltage (MV) and low voltage (LV) leads used in the model for magnetic field calculation with the leads and without winding. Table 8 gives the values of peak voltages applied to the high voltage (HV), middle voltage (MV) and low voltage (LV) leads used in the model for electric field calculation.

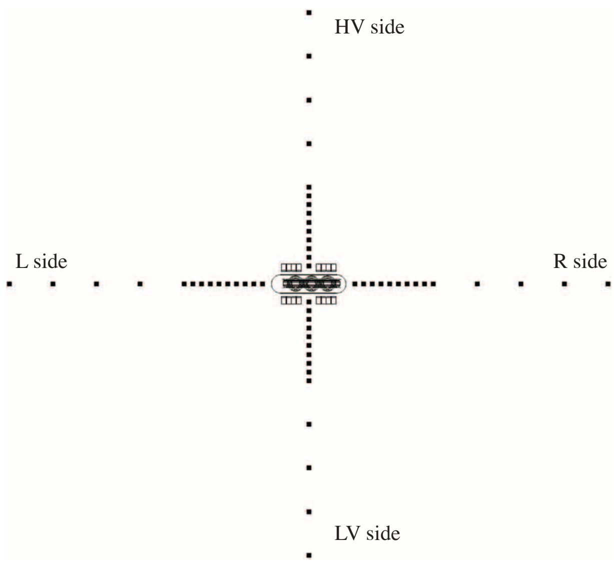

Figure 14. Top view of the transformer with marked calculation points, 220 MVA, 240 kV transformer.

Table 6. Peak ampere-turn values in the windings for the magnetic field model with windings, 220 MVA, 240 kV transformer.

	Peak ampere-turns	
	HV	MV
Phase 1	900000	-900000
Phase 2	-450000	450000
Phase 3	-450000	450000

Table 7. Values of peak current in the leads for the magnetic field model with leads, 220 MVA, 240 kV transformer.

	Peak current [A]	
	HV	MV
Phase 1	764	2700
Phase 2	-382	-1350
Phase 3	-382	-1350

Table 8. Values of peak voltage in the leads for the electric field model with leads, 220 MVA, 240 kV transformer.

	Peak voltage [V]	
	HV	MV
Phase 1	339411	96167
Phase 2	-169706	-48083
Phase 3	-169706	-48083

4.1. Magnetic field

Table 9. Peak values of calculated flux density in the surroundings of the 220 MVA, 240 kV transformer, part 1.

distance	point	Windings	Leads	Total
[m]		Bcalc[μT]	Bcalc[μT]	Bcalc[μT]
1	HV_01	35,05	37,46	72,52
2	HV_02	17,99	38,40	56,39
3	HV_03	7,63	27,72	35,35
4	HV_04	4,69	19,69	24,38
5	HV_05	2,60	13,44	16,04
6	HV_06	2,13	9,88	12,01
7	HV_07	1,26	7,21	8,47
8	HV_08	0,89	5,53	6,42
9	HV_09	0,68	4,16	4,84
10	HV_10	0,47	3,33	3,80
15	HV_15	0,17	1,22	1,39
20	HV_20	0,08	0,52	0,60
25	HV_25	0,04	0,28	0,33
30	HV_30	0,03	0,15	0,18
1	R_01	11,06	26,68	37,74
2	R_02	5,88	14,87	20,75
3	R_03	3,03	9,09	12,12
4	R_04	2,25	5,83	8,08
5	R_05	1,53	3,98	5,50
6	R_06	0,83	2,62	3,45
7	R_07	0,62	2,10	2,72
8	R_08	0,54	1,59	2,13
9	R_09	0,46	1,29	1,76
10	R_10	0,39	1,04	1,42
15	R_15	0,08	0,42	0,51
20	R_20	0,06	0,23	0,29
25	R_25	0,04	0,11	0,15
30	R_30	0,02	0,08	0,11

Table 10. Peak values of calculated flux density in the surroundings of the 220 MVA, 240 kV transformer, part 2.

distance [m]	point	Windings Bcalc[μT]	Leads Bcalc[μT]	Total Bcalc[μT]
1	LV_01	33,32	63,86	97,17
2	LV_02	16,63	53,50	70,13
3	LV_03	8,13	36,05	44,18
4	LV_04	3,81	23,84	27,66
5	LV_05	2,75	16,80	19,55
6	LV_06	1,50	11,66	13,16
7	LV_07	1,20	8,17	9,37
8	LV_08	0,94	6,19	7,13
9	LV_09	0,73	4,69	5,42
10	LV_10	0,52	3,70	4,22
15	LV_15	0,16	1,29	1,45
20	LV_20	0,10	0,52	0,62
25	LV_25	0,04	0,29	0,33
30	LV_30	0,04	0,15	0,18
1	L_01	9,99	19,98	29,97
2	L_02	6,72	11,42	18,13
3	L_03	3,59	6,74	10,33
4	L_04	0,61	4,56	5,17
5	L_05	1,16	3,14	4,30
6	L_06	0,99	2,42	3,41
7	L_07	0,84	1,86	2,70
8	L_08	0,60	1,48	2,08
9	L_09	0,47	1,22	1,69
10	L_10	0,36	0,99	1,35
15	L_15	0,12	0,36	0,48
20	L_20	0,05	0,21	0,26
25	L_25	0,04	0,12	0,16
30	L_30	0,03	0,09	0,11

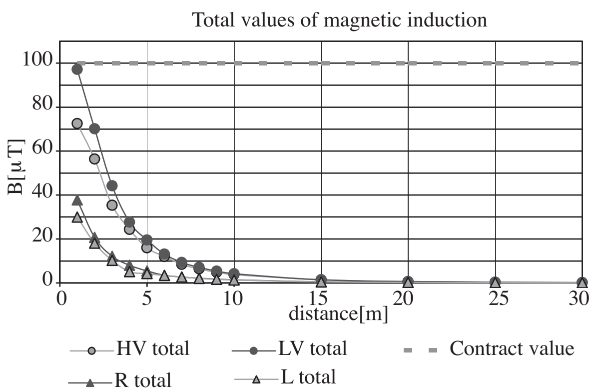

Figure 15. Calculated values of flux density in the surroundings of the 220 MVA, 240 kV transformer.

4.2. Electric field

Table 11. Peak values of calculated electric field outside the 220 MVA, 240kV transformer.

distance	point	Leads		distance	point	Leads
[m]		E[V/m]		[m]		E[V/m]
1	HV_01	1691		1	LV_01	1519
2	HV_02	2547		2	LV_02	2492
3	HV_03	1989		3	LV_03	1844
4	HV_04	1575		4	LV_04	1364
5	HV_05	1278		5	LV_05	967
6	HV_06	796		6	LV_06	699
7	HV_07	559		7	LV_07	614
8	HV_08	437		8	LV_08	396
9	HV_09	337		9	LV_09	394
10	HV_10	275		10	LV_10	240
15	HV_15	112		15	LV_15	102
20	HV_20	58		20	LV_20	50
25	HV_25	31		25	LV_25	26
30	HV_30	25		30	LV_30	36
1	R_01	3843		1	L_01	2315
2	R_02	2221		2	L_02	1438
3	R_03	1347		3	L_03	1076
4	R_04	885		4	L_04	786
5	R_05	612		5	L_05	559
6	R_06	536		6	L_06	472
7	R_07	356		7	L_07	379
8	R_08	286		8	L_08	289
9	R_09	223		9	L_09	203
10	R_10	183		10	L_10	183
15	R_15	78		15	L_15	79
20	R_20	41		20	L_20	40
25	R_25	23		25	L_25	20
30	R_30	15		30	L_30	13

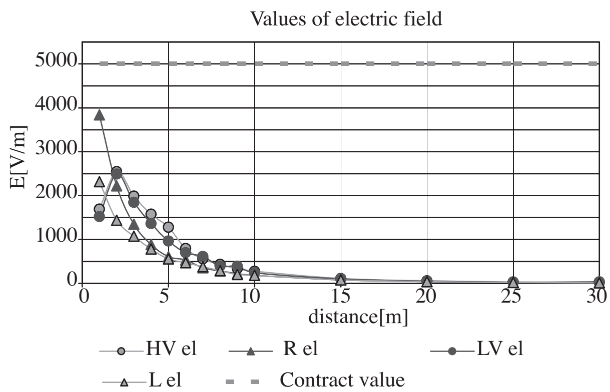

Figure 16. Calculated values of electric field outside of 220 MVA, 240 kV transformer.

As it can be seen from Tables 9 to 11 and Figures 15 to 16 the peak values of electric and magnetic are below the customer request of 5 kV/m and 100 μT respectively, not only at 30 m from the transformer, but across the whole range. It can also be noticed that the results are quite different in the close surrounding of the transformer compared to the previous case. The reasons for that difference lie in a different geometry of the two transformers: different amount of winding stray flux, lower position of the leads, and most importantly, there is a different layout of the cooling radiators which act as a shield to electromagnetic field. The 250 MVA transformer has the cooling radiators across the entire tank in both HV and MV sides, while 220 MVA transformer misses couple of radiators in the middle, just in the line with the calculation points on the HV and LV side. Therefore, the 220 MVA transformer does not have an electromagnetic shield in the form of cooling radiators resulting in higher field values in the first 5 meters from the transformer.

5. Conclusion

The presented analysis deals with the comparison of measured and calculated magnetic and electric field in the surroundings of a power transformer.

Although it is possible to calculate the field using a 3D finite-element model, the main difficulty is to get precise absolute values of magnetic flux density and electric field strength that can be confirmed by measurement. The relative difference between the measured and the calculated values in this case can be as large as 15 dB. The peak values of the flux density in the surrounding area of the transformer are typically below 25 μT, and those of the electric field below 500 V/m, which are both values that can be easily disturbed by parasitic influences in both the model and the actual environment, so the results shown in this paper can be considered acceptable.

It can also be noticed that objects in the transformer's surroundings have great impact on the magnetic and electric field distribution in the vicinity of the transformer. The values of electromagnetic field measured on site can differ significantly from those measured in the laboratory, so it can be concluded that the field in the surroundings of the transformer on site cannot be predicted reliably by measuring the field in the laboratory conditions. That applies to the model as well. For quantitative accuracy all parasitic influences must be known in advance, which is very difficult to achieve.

Computer modeling can be very useful to model just the transformer in an empty space. In that manner the influence of the transformer itself can be more easily distinguished from the influences of other sources of field once the transformer is on site.

References

[1] European Council Recommendation of 12 July 1999. on the limitation on exposure of the general public to electromagnetic fields (0 Hz to 300 GHz), 1999/519/EC.

[2] International Commission on Non-Ionizing Radiation Protection, Guidelines for Limiting Exposure to Time-Variant Electric, Magnetic and Electromagnetic Fields (up to 300 GHz), Health Phys.,Vol. 74, 4, (1998) 494-522.

[3] Zakon o zaštiti od neionizacijskog zraenja, Narodne novine 105/99, Croatia 1999.

[4] Z. Haznadar, Ž. Štih: Electromagnetic Fields, Waves and Numerical Methods, IOS - Press, Amsterdam, Berlin, Oxford, Tokyo, Washington, 2000.

[5] O. Hartal, M. Merzer: Magnetic shielding of power plants in large facilities, 2003. IEEE International Symposium on Electromagnetic Compatibility, pages 966 - 970 Vol. 2.