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Simulation of transfer of HF conductive disturbances from the primary to the secondary circuits of inductive current transformers in CM-CM coupling

Abstract. *This paper present the simulation of the transfer of electromagnetic disturbances from the primary to the secondary circuits of current transformers in CM-CM coupling in the frequency range [0.1 - 20MHz] . The primary voltage U1 of the primary winding equal to 30V was taken for the study of the two models of the current transformers in different configurations with and without screen to see its influence on the transmission of the disturbances, also to see the effect of capacitive couplings between the different CT elements. The simulation results obtained which represent the variation of the transfer function as a function of frequency gave us the maximum disturbance rate for each case.*

Streszczenie. *W artykule analizowano przejście zakłóceń elektromagnetycznych z uzwojenia pierwotnego do wtórnego przekładnika prądowego w zakresie częstotliwości 0.1 – 20 MHz. Analizowano też sprzężenie pojemnościowe między tymi uzwojeniami. Transmisja zakłóceń zależy od czestotliwości.* ***Analiza transmisji zakłóceń elektromagnetycznych HF miedzy pierwotnym a wtórnym uzwojeniem przekładnika prądowego***

Keywords: Current transformers(CT),EMC,Conductive disturbances,Common mode (CM),Differential mode (DM),Capacitive couplings.
Słowa kluczowe: przekładnik prądowy, zakłócenia elektromagnetyczne, sprzżenie pojemnościowe

Introduction

In its practical aspect, the most common causes of electromagnetic high-frequency (HF)disturbances in the primary circuits of instrument transformers are the following: lightning strokes, bursts of very short transients generated by the circuit switching operations, transient HF disturbances, as well as the continuous disturbances in the form of waves of wide frequency band. Instrument transformers (also electronic instrument transformers with inductive parts) [1,2], coupling the primary circuits with secondary circuits make possible propagation of electromagnetic disturbances. The values of the disturbances penetrating secondary circuits depend on the perturbations occurring in the primary circuits as well as on the degree of their damping by the instrument transformer. According to the Electromagnetic Compatibility (EMC) standard requirements [3], conducted disturbances should be limited and so simulated within the range of frequency [0.1-30MHz] . The surge rise times correspond to approximately the same frequency range. At high frequencies, all those phenomena have an influence on the transfer of disturbances to the secondary circuits. Electromagnetic couplings of an instrument transformer can also lead to the propagation of disturbances between structural elements (windings, shields, core, casing).

The analysis of conductive electromagnetic disturbances in energy systems from primary circuits to secondary circuits of measuring transformers in general and current transformers in particular and the way of its eliminations or reductions is a very important task from the point of view the performance of these devices and the quality of energy obtained in the different types of energy systems.

The ways and methods of reducing these disturbances depend on several factors and parameters ,and according to the work that has been done in this field, we see that :

1. In the paper [4], it is presented that the equivalent coupling capacities between the primary and the secondary sides of the voltage transformer are mainly dependent on the type of coupling eg Cm-dm or Dm-dm, through which the surges transfer takes place, and also depends on the secondary windings loads.

2. In the paper [5], it is presented that the equivalent diagram which contains the parasitic capacitances between the different elements of these devices as well as on the configurations of the primary and secondary windings to have less disturbances transferred to the secondary side .

3. In the papers [6,7] it is presented the change of the phase displacement of the primary voltage particular harmonic after transfer through a given voltage transformer.

4. In the papers [8,9,10], it is presented the change of the parameters of the equivalent circuit of the CTs for the reduction of disturbances transmitted to the secondary circuits.

5. In the papers [11,12], it is presented the he characterization of voltage instrument transformers . The method is based on the concept of best linear approximation of a nonlinear system and on the value and the type of the loads of the secondary sides, frequency and value of primary voltages .

In this paper, two models of identical current transformers without and with screen have been realized.

The results of the experimental testing [13], prove though that the transfer of CM signals is far more significant than the DM signals because the electromagnetic disturbances couple weakly in differential mode (DM) compared to the common mode(CM), then the study will be done only on the mode of coupling (CM-CM).

The parasitic capacitance parameters were measured according to the equivalent diagram and the Matlab software simulation of the U2 / U1 transfer function in the frequency band [0.1 - 20MHz] was performed for different configurations of the models in the coupling mode CM-CM.

For each case of the simulation, the maximum rate of the disturbances transferred to the secondary circuit is determined. Best results from the point of view of suppression of these disturbances are chosen taking into consideration values of parasitic capacitances of the equivalent diagram of the CT and the connections of the screen and the core to the ground.

Figures 1, 2, show respectively developed model and the structure of the parasitic capacitances that play the most important role in transfer of conductive disturbance in the current transformers without screen [14].

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ig.1. Developed model of inductive current transformer

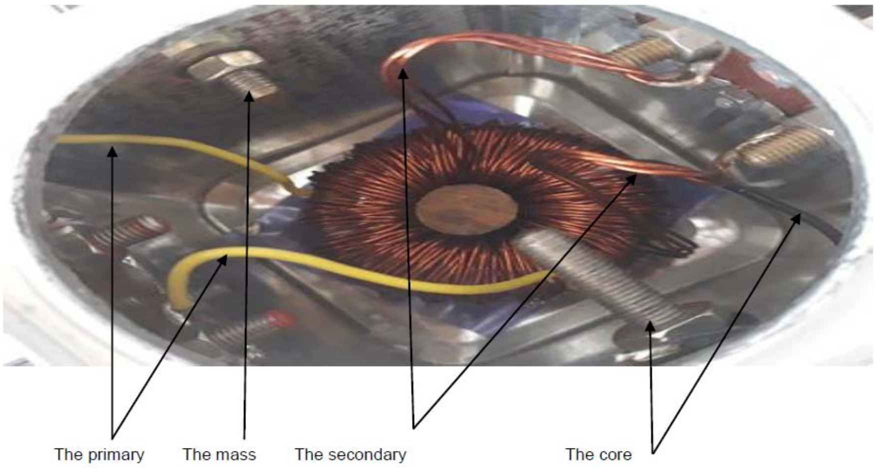


Fig.1. Developed model of inductive current transformer

Construction of the two models:
• Close template type 100 x 100 x 100 mm,
• 2U type core with gap (ET material),
•Type A casing (presspahn) - 1 piece,
•The secondary winding (Z_2 = 2000 turns are wound directly on the carcass), 11 layers of wires DN2E ~ 0.35 mm,
•The primary winding (Z_1 = 170 turns are wound on the secondary winding), 4 layers of wires DN2E ~ 1.55 mm,
• Insulation (estrofol),
• Screen (copper sheets).

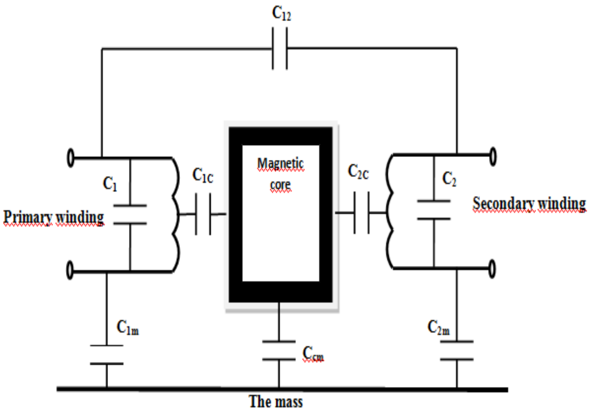


Fig.2. Simplified equivalent circuit of inductive CT(without screen) for representation of the capacitive couplings for HF conductive disturbances

Parameters:
• C_{12} : capacitance between primary winding and secondary winding;
• C_1,C_2 : capacitances between terminals of the windings;
• C_{1C} : capacitance between primary winding and the core;
• C_{2C} : capacitance between secondary winding and the core;
• C_{1m} : capacitance to mass of the primary winding;
• C_{2m} : capacitance to mass of the secondary winding;
• C_{cm} : the capacitance to mass of the core.

The mode of coupling CM-CM that exist between the primary circuit and the secondary circuit of the current transformers is presented by the following figure :

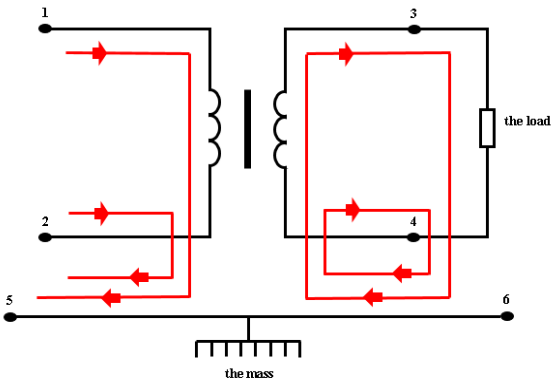


Fig.3. CM-CM coupling from primary to secondary circuits of CT

Models of current transformers used for the simulation

Two previously presented CT models are used to determining the degree of transfer of conductive disturbances of frequencies [0.1–20MHz] to their secondary circuits.

However, it considers those phenomena, which have a decisive influence on disturbance penetration from primary to secondary circuits of current transformers. Parasitic capacitances can be determined according to the method developed bellow (measurement of parasitic capacitances of CT models).

It concerns measurements of the equivalent capacitances between the CT and the mass in all the possible arrangements of their direct electrical connections.The solution of the received system of equations gives values of the parasitic capacitances of inductive CT.

The following figures show the two models of CT with and without screen used for simulation.
We have the following equations:

(1) $U_1 = U_g - Z_g \cdot I$

(2) $U_2 = Z_0 \cdot I$

(3) $U_{L1} = j\omega L_1$

(4) $U_{L2} = j\omega L_2$

(5) $U_{Ls} = j\omega L_s$

(6) $U_{Lc} = j\omega L_c$

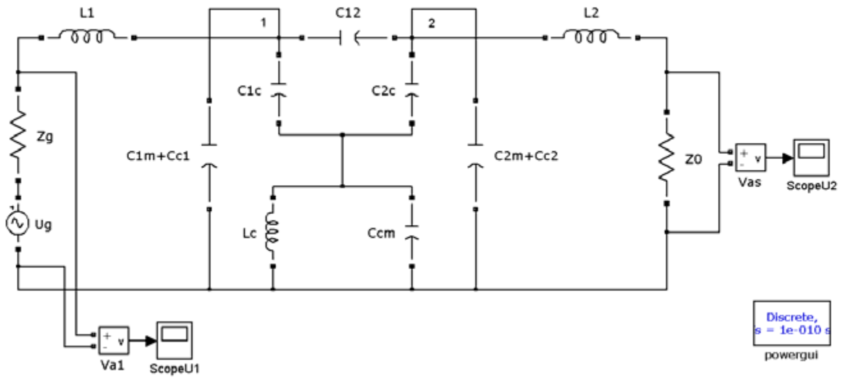


Fig.4. Model of the CT without screen for the simulation of the coupling(CM-CM)

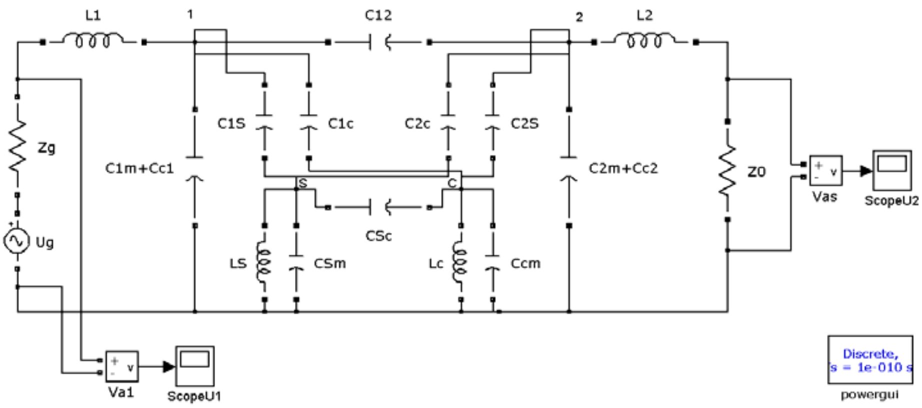


Fig.5. Model of the CT with screen for the simulation of the coupling(CM-CM)

(7) $U_{Cij} = \dfrac{1}{J\omega Cij}$ (i,j = 1,2,m,c,s)

where: *1*- the primary, 2 - the secondary, m - the mass, c - the core, s - the screen.

(8) $\omega = 2\pi F$; F is the frequency.

(9) $\dfrac{U_1}{U_2} = f(F)$ is a transfer function that depends of F and the others parameters of the models.

Parameters of the two models:

- U_1 : The primary voltage ;
- U_2 : The secondary voltage ;
- L_1 : The primary inductance;
- L_2 : The secondary inductance;
- S : The screen;
- C : The core;
- Z_g = R_g :The internal resistance of the generator;
- Z_0 : The load;
- C_{12} :The capacity between the primary and secondary winding;
- C_{c1} : The capacity of the primary measuring conductor;
- C_{c2} :The capacity of the secondary measuring conductor;
- L_s : The inductance of the conductor which links the screen with the mass;
- L_c : The inductance of the conductor which links the core with the mass;
- C_{1m} :The capacity between the primary winding and the mass;
- C_{2m} :The capacity between the secondary winding and the mass;
- C_{cm} : The capacity between the core and the mass;
- C_{sm} : The capacity between the screen and the mass;
- C_{1S} :The capacity between the primary winding and the screen;
- C_{2S} :The capacity between the secondary winding and the screen;
- C_{sc} :The capacity between the screen and the core;
- C_{1c} :The capacity between the primary winding and the core;
- C_{2c} :The capacity between the secondary winding and the core.

Measurement of parasitic capacitances of CT models

The two models of current transformers have been shown to measure parasitic capacitances by the following figures:

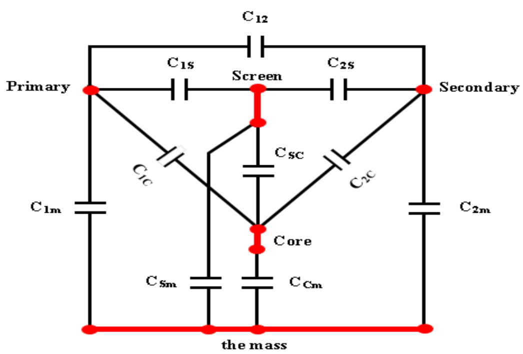


Fig.6. Parasitic capacitances of inductive CT with screen

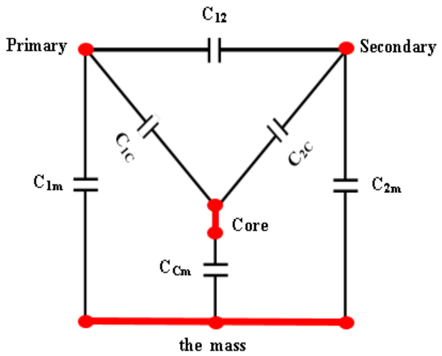


Fig.7. Parasitic capacitances of inductive CT without screen

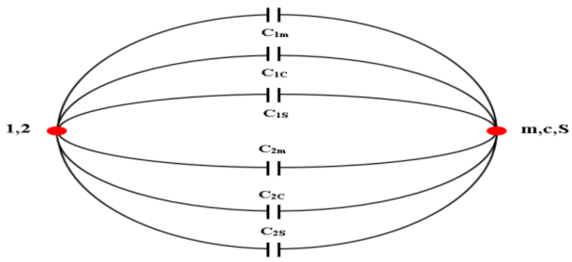
The determination of parasitic capacitances is a task that can not be realized between two different elements (eg between the primary and secondary windings). If we do this kind of measurement, we will make an error because of the existence of other capacitive couplings between these 2 elements that we have already mentioned. The result of this measurement leads to know the equivalent capacity.

To make an exact measurement, we follow the following method:

In figure 6, the primary 1 has been short-circuited with the secondary 2, i.e: a point (1,2) has been obtained, then the other elements of the circuit have been short-circuited together; the mass m, the core c and the screen s, i.e: the other point of the circuit (m,c,s) has been obtained. Therefore, the parasitic capacitances that remain between the points (1,2) and (m,c,s) are C_{1m}, C_{1c}, C_{1s}, C_{2m}, C_{2c}, C_{2s}.

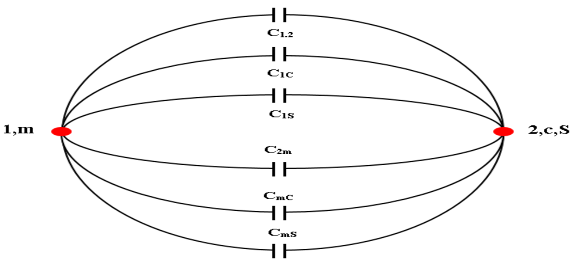
These parasitic capacitances are connected together in parallel (see figure 8), which implies that the measurement of the equivalent capacitance between the points (1,2) and (m,c,s) will present the sum of these capacities (equivalent capacity). In other words $C_{1m} + C_{1c} + C_{1s} + C_{2m} + C_{2c} + C_{2s} = 506pF$ [value measured between points (1,2) and (m,c,s)].We followed the same path for the other combinations and each time we get an equation.

At the end we obtain a system of equations with unknowns which represent the parasitic capacitances of the circuit.



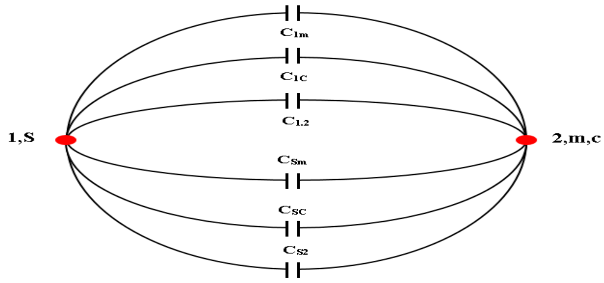
$C_{1m}+ C_{1c} +C_{1s} + C_{2m} + C_{2c} +C_{2s} = 506pF$

Fig.8. Measurement of the equivalent **capacitance** between the short- circuited points (1,2) and (m,c,s)



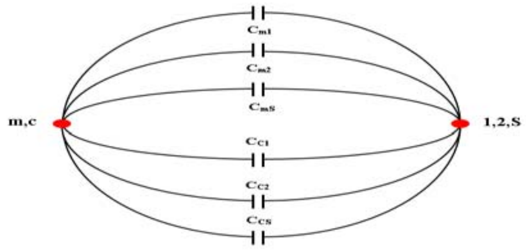
$C_{12}+ C_{1c} +C_{1s} + C_{2m} + C_{mc} +C_{ms} = 350pF$

Fig.9. Measurement of the equivalent capacitance between the short-circuited points (1,m) and (2,c,s)



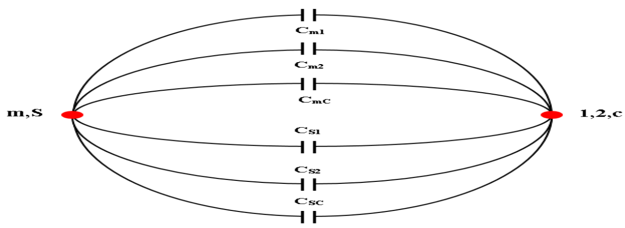
$C_{1m} + C_{1c} +C_{12} + C_{sm} + C_{sc} +C_{2s} = 189pF$

Fig.10. Measurement of the equivalent capacitance between the short-circuited points (1,s) and (2,m,c)



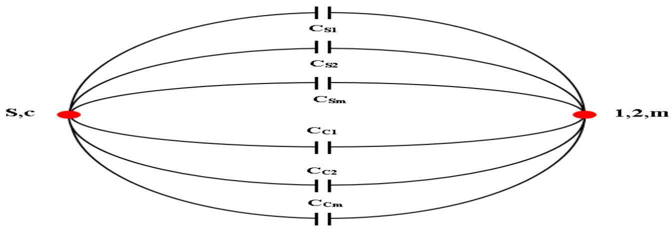
$C_{m1}+ C_{m2}+C_{ms}+ C_{c1}+ C_{c2}+C_{cs} = 106pF$

Fig.11. Measurement of the equivalent capacitance between the short-circuited points (m,c) and (1,2,s)



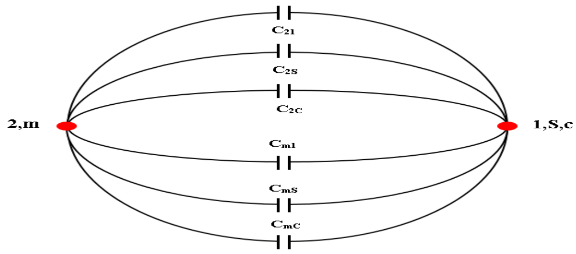
$C_{m1} + C_{m2}+C_{mc}+ C_{s1}+ C_{s2}+C_{sc} = 474pF$

Fig.12. Measurement of the equivalent capacitance between the short-circuited points (m,s) and (1,2,c)



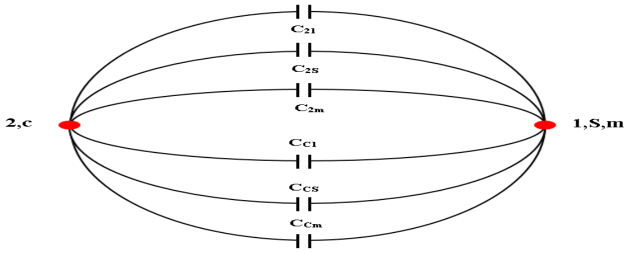
$C_{s1} + C_{s2}+C_{sm}+ C_{c1}+ C_{c2}+C_{cm} = 521pF$

Fig.13. Measurement of the equivalent capacitance between the short-circuited points (s,c) and (1,2,m)



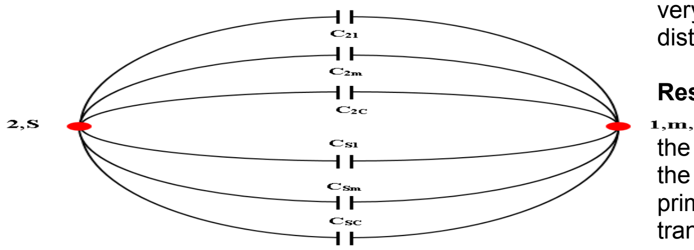
$C_{21} + C_{2s}+C_{2c}+ C_{m1}+ C_{ms}+C_{mc} = 245pF$

Fig.14. Measurement of the equivalent capacitance between the short-circuited points (2,m) and (1,s,c)



$C_{21} + C_{2s} + C_{2m} + C_{c1} + C_{cs} + C_{cm} = 184pF$

Fig.15. Measurement of the equivalent capacitance between the short-circuited points (2,c) and (1,s,m)



$C_{21} + C_{2m} + C_{2c} + C_{s1} + C_{sm} + C_{sc} = 376pF$

Fig.16. Measurement of the equivalent capacitance between the short-circuited points (2,s) and (1,m,c)

The parameters of figures 6, 7 are measured by a MASTECH MS8217 Digital Multimeter.

Figures (8 - 16) show the capacitive coupling between the elements of the model with screen for different connection systems.

So, we got a linear equation system:

$$
\begin{aligned}
&C_{1m} + C_{1c} + C_{1s} + C_{2m} + C_{2c} + C_{2s} = 506pF \\
&C_{12} + C_{1c} + C_{1s} + C_{2m} + C_{mc} + C_{ms} = 350pF \\
&C_{12} + C_{1m} + C_{1s} + C_{2c} + C_{cm} + C_{cs} = 381pF \\
&C_{1m} + C_{1c} + C_{12} + C_{sm} + C_{sc} + C_{2s} = 189pF \\
&C_{1m} + C_{2m} + C_{mc} + C_{1c} + C_{2c} + C_{cs} = 106pF \\
&C_{1m} + C_{2m} + C_{mc} + C_{1s} + C_{2s} + C_{sc} = 474pF \\
&C_{1s} + C_{2s} + C_{sm} + C_{1c} + C_{2c} + C_{cm} = 521pF \\
&C_{12} + C_{2s} + C_{2c} + C_{1m} + C_{ms} + C_{mc} = 245pF \\
&C_{12} + C_{2s} + C_{2m} + C_{1c} + C_{cs} + C_{cm} = 184pF \\
&C_{12} + C_{2m} + C_{2c} + C_{1s} + C_{sm} + C_{sc} = 376pF
\end{aligned}
\tag{10}
$$

The system (8) was solved using the matrix method and the following results were obtained:

$$
\begin{aligned}
&C_{12} = 6\,pF \\
&C_{1m} = 15.5 \\
&C_{2m} = 9\,pF \\
&C_{1c} = 10\,pF \\
&C_{2c} = 48\,pF \\
&C_{1s} = 285.5\,pF \\
&C_{2s} = 135\,pF \\
&C_{sm} = 18\,pF \\
&C_{sc} = 5.5\,pF \\
&C_{cm} = 19.5\,pF
\end{aligned}
\tag{11}
$$

For the model without screen, the following results were obtained following the same method of measurement:

$$
\begin{aligned}
&C_{12} = 77.5\,pF \\
&C_{1m} = 10\,pF \\
&C_{2m} = 12\,pF \\
&C_{1c} = 7\,pF \\
&C_{2c} = 70.5\,pF \\
&C_{cm} = 27.5\,pF
\end{aligned}
\tag{12}
$$

Parameters of the parasitic capacitances obtained are very essential from the point of view of the transfer of disturbances in the CM-CM coupling mode.

Results and analysis

The results obtained from the computer simulation in the Matlab software enables the possibility for evaluation of the value of conductive disturbances transfer from the primary circuits to the secondary circuits of current transformers in CM-CM coupling mode for different configurations.

The results of the simulation for each case are shown in figures 17-26.

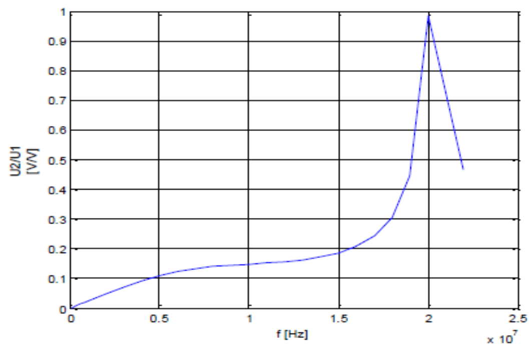


Fig.17. The core is connected to the mass(without screen)

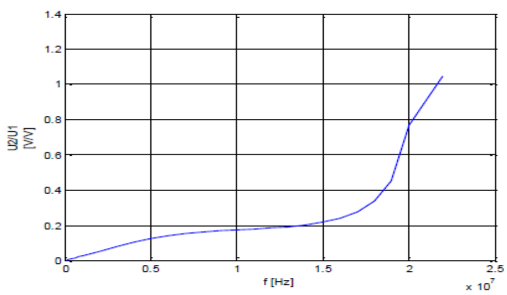


Fig.18. The core is not connected to the mass(without screen)

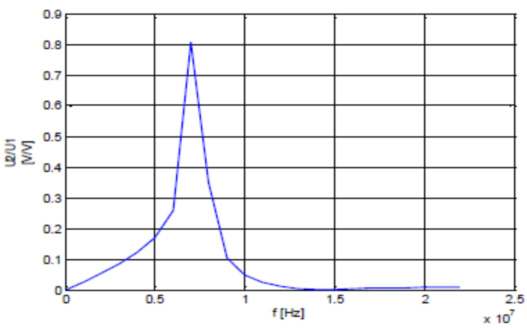


Fig.19. The screen and the core are not connected to the mass

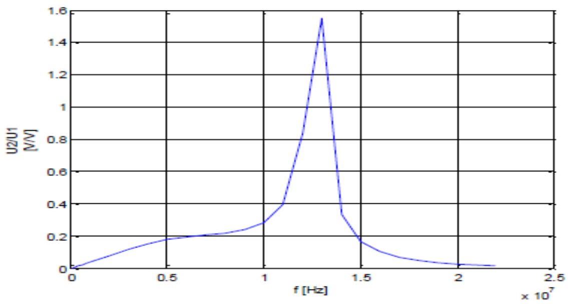


Fig. 20. The core is connected to the mass and the screen is not connected

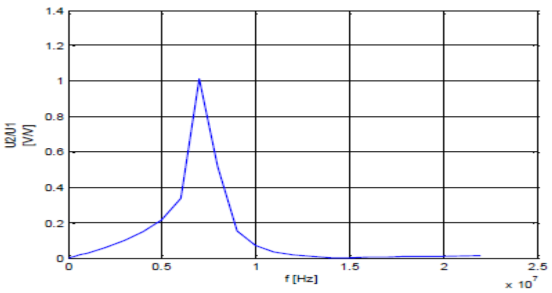


Fig.21. The screen is connected to the mass and the core is not connected

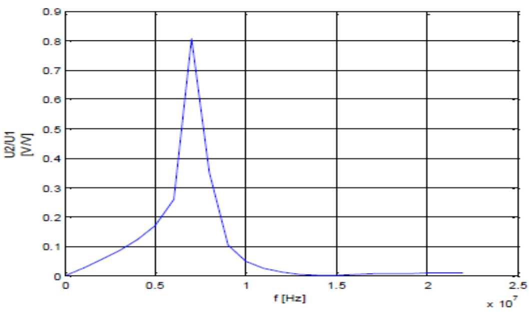


Fig.22. The core and the screen are connected to the mass

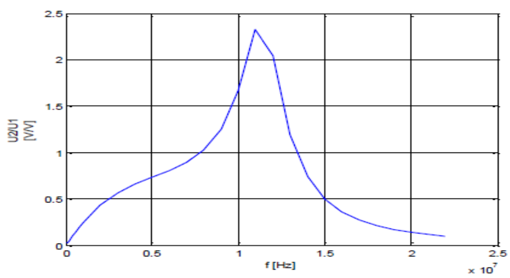


Fig.23. The core is connected to the mass(C_{12}= 10 times more) (without screen)

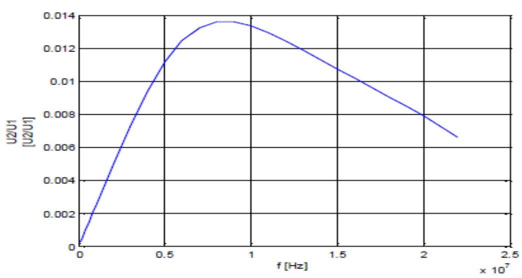


Fig.24. The core is connected to the mass(C_{12} = 10 times less) (without screen)

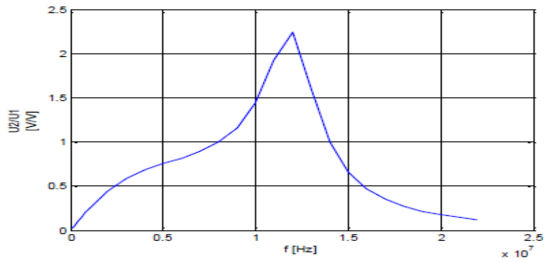


Fig.25. The core is not connected to the mass(C_{12}=10 times more) (without screen)

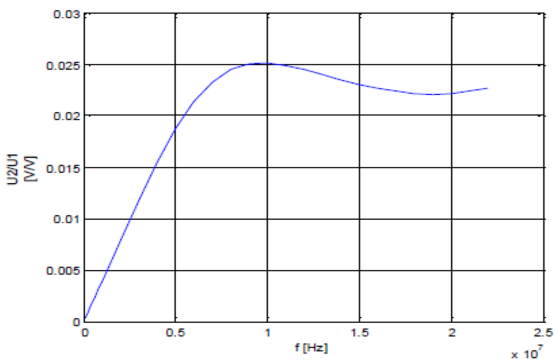


Fig.26. The core is not connected to the mass(C_{12}=10 times less) (without screen)

According to the results of simulation:

Based on obtained results of simulation following observations can be make:

1.We can see that the minimum disturbance rate is in these cases: "the screen and the core are not connected to ground" and "the screen and the core are connected to ground" which implies that the connection of these two elements to the mass is not important because its rates of disturbances are the same, but their presence in the construction of CTs is essential.

2.The maximum points represent the points of resonances because of the existence of the inductances.

3. The influence of the value of the parasitic capacitance C_{12} on transfer of conductive disturbances can be determined from the difference between presented results in Figures 23 and 24.

4. There is no detected influence of values of other than C_{12} parasitic capacitances on transfer of conductive disturbances

5.The connection of the core to the mass plays an important role towards the transmission of disturbances to the secondary side.

6.The two cases: "no connection between the screen and the mass " and " connection between the core and the mass" influence enormously on the transfer of the perturb ation.

7.The value of the capacity C_{12} is the most influential parameter in comparison with the others concerning the intensity of the transfer of perturbations . See Figures 23, 24,25,26.

Conclusion

High values of transferred conductive disturbances may became a threat to proper operation of measuring and protection apparatus connected to the secondary circuit of inductive current transformers. To decrease their level of electromagnetic immunity, the accuracy of their measurement protection. Besides, the value of the transfer factor is reduced and the harmonic phase shift increases.

Obtained results of simulation allow to conclude that the construction and connection of the elements of current transformers to the ground : the core and the screen, and their parasitic capacitance values influence the transmission of disturbances. As we see that the maximum rate of disturbances transferred for the cases "connected and non-connected to the mass" for the conventional model without screen reaches about 100% which implies that the connection to the mass of the core does not influence the intensity of the transmission of the electromagnetic disturbances. On the other hand, the other case "with screen" is strictly different from the first, ie the maximum rate reaches about 80% which implies the important role of the screen about the transfer of disturbances to the secondary circuits of CTs.

The model with the configuration "The core and the screen are connected to the mass" is better from the point of view of disturbance transfer in comparison with other configurations because the maximum rate reaches about 80%.

In Figures 23 and 24, we see that the efficiency of parasitic capacitance C_{12} is enormous because the maximum rates reach respectively 225% and 1.4% (a big difference between the two cases).

Finally, the essential points that have been realized are:

1. The possibility of the determination and measurement of CT parameters particularly the parasitic capacitances to test their positive or negative influences on the transfer of disturbances from the primary circuits to the secondary circuits.

2. The reduction of the electromagnetic disturbances depends enormously on the capacity C_{12} .

3. The ideal construction of these devices according to the Electromagnetic Compatibility(EMC) depends enormously on these parameters.

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