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ANALYSIS OF CONDUCTIVE INTERFERENCE, ON ELECTRONIC EQUIPMENT, DUE TO LOW FREQUENCY CURRENTS FLOWING THROUGH THE EARTHING INSTALLATION

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ABSTRACT

The present report deals with some EMC problems relative to the interferences involving earthing installations. In particular, 50÷60 Hz conductive interferences are examined, in order to evaluate how they can cause malfunctions of those electronic systems which are very susceptible to external influences.

To this purpose, two different configurations of earthing system are analysed, chosen among those more frequently used.

The computation of the current derived from each single part of the earthing system (in normal condition and in short-circuit condition) and the corresponding elaboration of the equivalent electric circuit allow to estimate the magnitude of such interferences as voltages between different points of the earthing system.

This evaluation, account taken of the electronic systems earthing modality, leads to a significant determination of the most critical situations of possible electronic malfunctions related to the connection to the earthing system.

CONSIOERATIONS ON CONDUCTIVE INTERFERENCES INVOLVING THE EARTHING SYSTEM

Usually, an interference is considered "conductive" if it is produced on the supply network of the equipment and transmitted through the same network.

Likewise, a noise caused by an electro-magnetic field far from the equipment and conductively transmitted to an electronic device is considered a conductive interference.

Most electronic systems are connected to the supply network, so that the electric and earthing installations become typical paths for the transmission of conductive interferences.

Noises can be classified as:

- *common-mode interference*, when an interference voltage appears between a phase and the neutral (in monophase systems, between phase or neutral and the earth);
- *differential-mode interference*, when an interference voltage appears between different phases (in monophase system, between the phase and the neutral).

In normal conditions, conductive interferences can be caused from leakage current of the equipment connected to the earthing installation; this current, due for example to filter capacitors, assumes a low value and therefore can flow permanently. Conductive interferences can happen also when a unique conductor is utilised as a common return for different circuits.

In fault conditions, conductive interferences can be caused by a short-circuit current flowing in the earthing system; the current value is higher and its duration depends on the circuit-breakers operating time.

EARTHING INSTALLATIONS

Two different configurations of earthing installations, commonly used in Italian electric installation, have been analysed.

TT earthing installation

For users supplied at low voltage (400 V), the earthing system often consists of a simple copper plait with some electrodes. In the present paper, a 35 mm² copper plait is considered (20 m long), with two zinc plated steel earth electrodes (1,5 m long) at its ends, as shown in figure 1.

The alternative current injection points are indicated by the arrows.

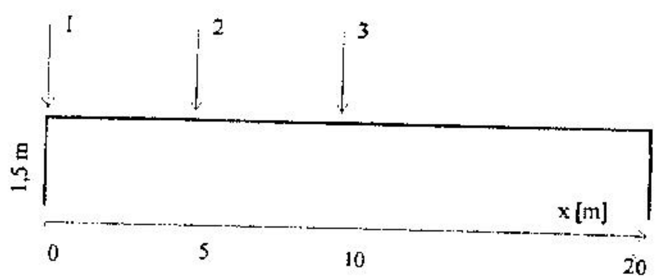

FIGURE 1 - A TT EARTHING INSTALLATION

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TN earthing installation

For users supplied at medium voltage (15÷22 kV), the earthing systems generally consists in a ring with earth electrodes at its corners, a first copper plait with earth electrodes for the loads and a second copper plait connecting the previous parts.
In the present paper, copper plaits and zinc plated steel earth electrodes having the same characteristics of the previous situation are assumed; their dimensions, the geometrical disposition and the alternative current injection points are shown in figure 2.

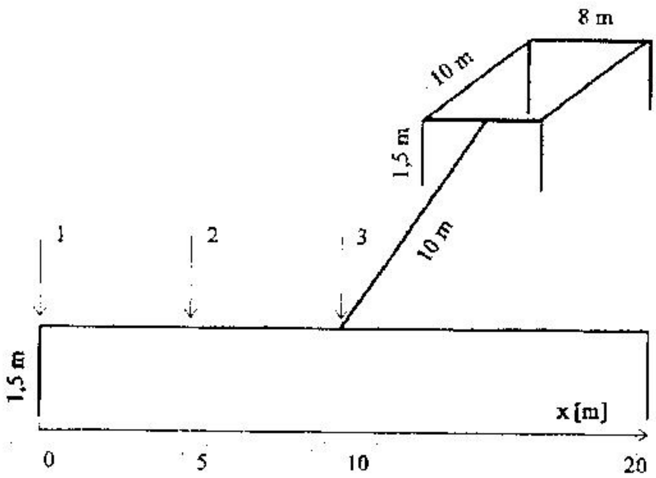

FIGURE 2 - A TN EARTHING INSTALLATION

EARTHING INSTALLATION BEHAVIOUR

To analyse the earthing installation behaviour it has been used a computation routine, based on Maxwell's sub-areas and images method ([1]), which it's possible to describe synthetically every earthing system without any limit of shape and extension.
The earth can be heterogeneous, e.g. composed by two parallel layer with different resistivity.

From the analogy between electrostatic-field and current-field, a linear equations system follows, solvable by a PC.

Initially, in each situation it has been assumed the same earthing system depth (0,5 m) and homogeneous earth (100 Ωm).

Elements of the earthing system: evaluation of the current sharing and earth resistance

Initially, each point of the earthing system is considered at the same voltage, apart from the current injection point.

The used computation routine requires to subdivide the earthing installation into n elements (the higher is n, the better is the result approximation), and allows to calculate the total voltage V_T, the total earth resistance R_T and the share of current derived from each single part in which the earthing system has been subdivided.

Consequently, the earth resistance of each element R_{Ti} is given by the following relation:

$$R_{Ti} = \frac{V_T}{I_i} \qquad (1)$$

([1]) Computation routine realized by Dott. Patrocco, Enel SpA - Compartimento di Torino

Electric circuit equivalent of the earthing installation

The so obtained parameters allow to determine the electric circuit equivalent of the earthing installation.

On the basis of the longitudinal resistance R_L of the conductors (1,2 Ω/km for the 35 mm² copper plait and 0,5 Ω/km for the earth electrodes) and the earth resistance R_{Ti}, for each element forming the earthing installation there is an "L" equivalent electric circuit; the union of the "L" circuits gives the equivalent electric circuit of the earthing system.

For example, figure 3 shows a TT earthing installation structure, the relative subdivision and the equivalent electric circuit of some elements.

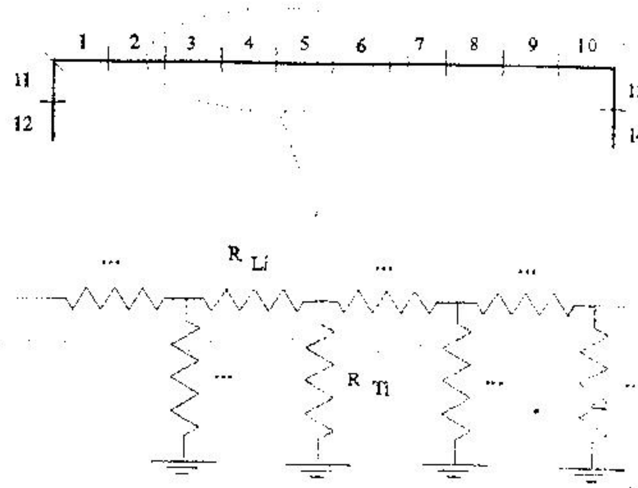

FIGURE 3 - SUBDIVISION AND EQUIVALENT ELECTRIC CIRCUIT OF A TT EARTHING SYSTEM

The following table I shows the characteristics values of the TT earthing installation elements, based on the subdivision shown in figure 3 and a 1000 A short-circuit current value.

TABLE I - CHARACTERISTICS OF A TT EARTHING INSTALLATION ELEMENTS

element n°	RLi [mohm]	VT [V]	Ii [A]	RTi [ohm]
1	2,4	7673	80	96
2	2,4	7673	80	96
3	2,4	7673	79	97
4	2,4	7673	78	98
5	2,4	7673	78	98
6	2,4	7673	78	98
7	2,4	7673	78	98
8	2,4	7673	79	97
9	2,4	7673	80	96
10	2,4	7673	80	96
11	0,375	7673	48	160
12	0,375	7673	56	136
13	0,375	7673	48	160
14	0,375	7673	56	136

Approximations

The above explained method, used to analyze the behaviour of earthing installations, is affected by some approximations.

In particular, it is important to underline the following points:

- the copper plaits and the electrodes, considered initially at the same potential, cause voltages between different elements of the installation, depending on the value and on the current injection point. These voltages can represent an interference for the electronic equipment connected to the earthing system.
- the expression (1), giving the earth resistance R_{Ti} of each element forming the earthing installation, doesn't consider the mutual influence among different elements.

COMPUTATION OF THE VOLTAGE BETWEEN DIFFERENT POINTS OF THE EARTHING INSTALLATION

On the base of the electric circuit equivalent of the earthing system, it is interesting to evaluate the voltages between different elements of the installation caused by a current injection in a predetermined point.

The circuit behaviour analysis has been realised with a routine fit to resolve meshed network.

Voltages corresponding to normal condition of the electric installation

It has been examined the case of a 100 mA current permanently derived by the earthing system because of the leakages of the connected electronic equipment.

The following figure 4 shows the case of a TT earthing system. The diagrams, corresponding to different current injection points (as represented in figure 1), give the voltage between a generic point of the copper plait and the injection point, conventionally assumed as potential reference (left scale).

It is interesting to observe that the higher is the distance from the injection point, the smaller is the voltage per meter of conductor, because of the increasing current share already derived to earth.

Furthermore, the asymmetry of diagrams 2 and 3 in respect of the current injection point is caused by the current partition, which is proportional to the inverse of the equivalent resistance.

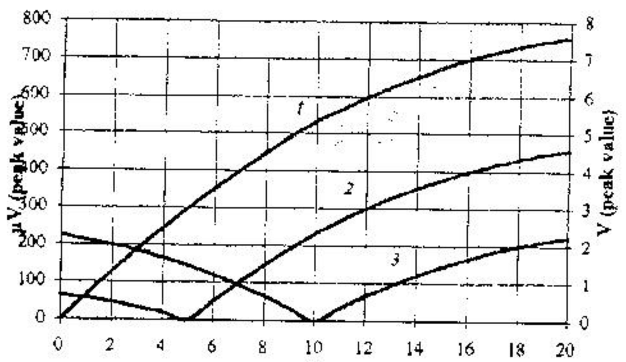

FIGURE 4 - VOLTAGES IN A TT EARTHING INSTALLATION

In the case of a TN earthing system, one more observation can be made. As shown in figure 5 (left scale), for x<10 m the voltage per meter abruptly decreases, because of the current share drained by the transformer room earthing installation (diagrams 1 and 2).

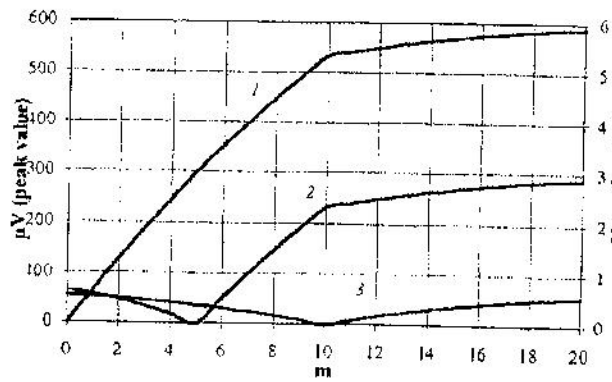

FIGURE 5 - VOLTAGES IN A TN EARTHING INSTALLATION

Voltages corresponding to short-circuit conditions of the electric installation

The earthing installation behaviour is supposed to be linear: so, neglecting the short-circuit transient, only the value of the current is changed in respect of the previous situation.

The voltages between different points of the earthing system increase proportionally, as shown in the same figures 4 (TT earthing system) and 5 (TN earthing system), related to the case of a 1000 A short-circuit current (right scale).

EARTH RESISTIVITY INFLUENCE

The voltages indicated in figures 4 and 5 have been calculated on the base of a reference value ρ =100 Ωm of the earth resistivity.

It is possible to demonstrate that the earth resistivity influence on the voltages between different points of the earthing installation is negligible.

To this purpose, it has been considered the example shown in figure 6, in which a simple circuit is shown, which represents a 35 mm² copper plait earthing system (20 m long) subdivided in two elements only.

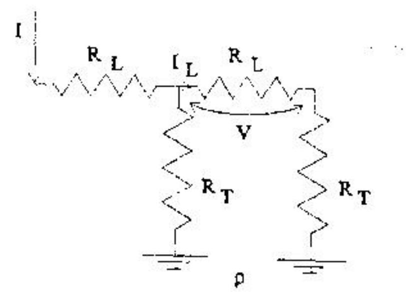

FIGURE 6 - EARTH RESISTIVITY INFLUENCE: REFERENCE CIRCUIT

From the circuit analysis it results:

$$VV = R_L I_L = R_L I \frac{R_T}{R_L + 2R_T} \cong R_L I \frac{R_T}{2R_T} = \frac{R_L I}{2}$$

It follows that the smaller is the longitudinal resistance R_L in respect of the earth resistance R_T, the smaller is the earth resistivity influence on the voltage V.

Anyway, the relationship $V(\rho)$ can be expressed, on the assumption that the function $R_T(\rho)=k\rho$ is linear. It results.

$$VV = R_L I \frac{k\rho}{R_L + 2k\rho}$$

The following diagram A (figure 7) shows the per-unit voltage variance (related to the reference situations ρ =100 Ωm) corresponding to a given range of ρ.

Similar conclusions can be reached for the situation of unhomogeneous earth, formed by two layers having different resistivity values. The diagram B, dashed in figure 7, shows the per-unit voltage variance for a superficial earth layer with ρ=100 Ωm (2 m deep), and a deep layer having varying resistivity.

In both cases the per-unit voltage variance is negligible.

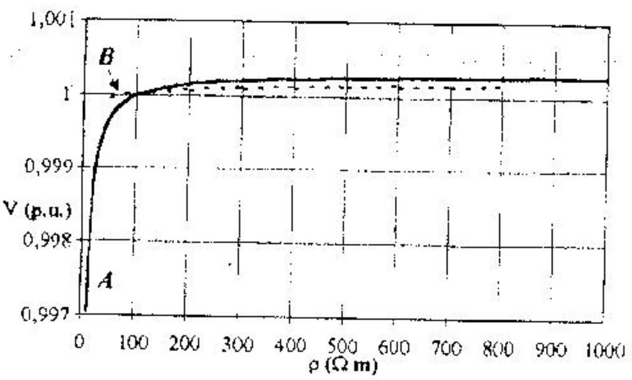

FIGURE 7 - PER-UNIT VOLTAGE VARIANCE DEPENDING ON EARTH RESISTIVITY

Similar computations made for the cases of the considered earthing installations, with smaller elements and better approximation, lead to the same results.

CONCLUSIONS

The following considerations can help to evaluate whether the conductive interferences analysed in the present report can cause malfunctions of electronic equipment connected to different points of the earthing installation.

- Generally, low-frequency conductive interferences don't cause any problem to electronic equipment.
- In the case of floating systems (figure 8) the voltage between different points of the earthing installation doesn't represent a noise for the signal.

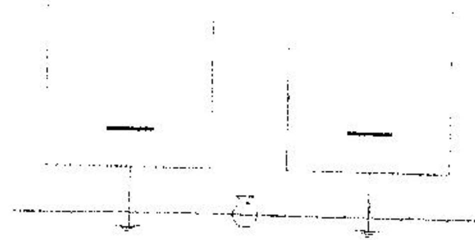

FIGURE 8 - FLOATING SYSTEM

- Similarly, for single-point earthing (figure 9) any malfunction can be excluded, as each potential moves in the same way.

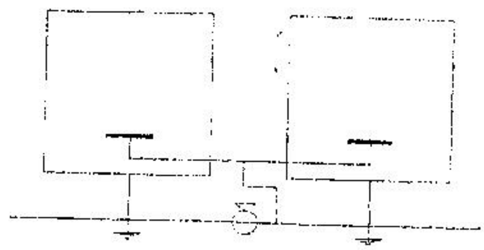

FIGURE 9 - SINGLE-POINT EARTHING

- In multi-point earthing (figure 10), used as a return way for equipment signals, the voltages between different points of the earthing installation are in series with the signal. In this case the voltages due to short-circuit currents can cause electronic equipment malfunctions, while voltages due to leakage currents are not high enough to determine any malfunction. Yet, a dedicated conductor used as a return path for the equipment signals can weaken interferences and make them negligible.

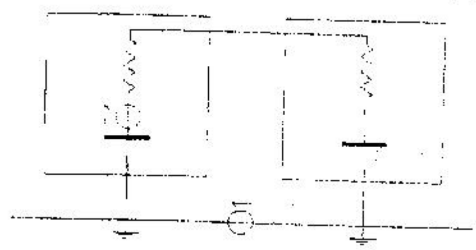

FIGURE 10 - MULTI-POINT EARTHING

Finally, the results of the present research can be resumed in the following way.

- For electric systems in normal condition, the leakage currents are so small that the consequent voltages between points of the earthing installation (some hundreds of microvolt) are not harmful also for the most susceptible electronic equipment.
- For electric systems in short-circuit condition, the fault currents can cause voltages of some volts between points of the earthing installation. Anyway, possible malfunctions can be avoided using proper earthing techniques for the electronic equipment (figure 11).

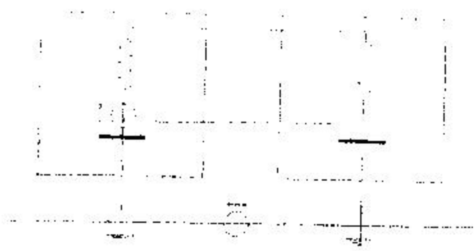

FIGURE 11 - DEDICATED CONDUCTOR USED AS A RETURN PATH FOR THE EQUIPMENT SIGNALS

- The earth resistivity represents a negligible parameter, because it notably changes the total voltage, but it doesn't modify the voltages between different points of the earthing installation.

References

Buccheri P., Cataliotti V., and Morana G., 1977, "Calcolo automatico di impianti di terra in terreni omogenei e non omogenei a doppio strato - Primi risultati di una indagine sistematica su dispersori per stazioni AT/MT e cabine MT/BT.", L'Energia Elettrica, N. 6, pp. 293÷304.

Buccheri P., Cataliotti V., and Morana G., 1975, " Un nuovo metodo per il calcolo automatico di impianti di terra comunque complessi in terreni e non omogenei a doppio strato", Simposio sugli impianti di terra - AEI, Sezione di Palermo.

Carrescia M., and Molina G., 1995, "Messa a terra delle apparecchiature elettroniche: stato dell'arte e sviluppi futuri", Riunione Annuale AEI, Roma, Vol. I.

Mardiguian M., 1988 "Electromagnetic interference and compatibility - Grounding and bonding - Volume 2".