ALTERNATIVE MATERIALS IN THE DESIGN OF GROUNDING ELECTRODES FOR TRANSFORMATION CENTERS IN BUILDING

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Abstract

In the design of grounding systems for transformation centers located in buildings for different uses (industrial, residential, etc.), electrodes made up basically of copper are usually used. This material has a great advantage from the electrical point of view as it is a magnificent conductor, but it has other major drawbacks such as its high cost and the continuous problems of vandalism or theft. These situations can cause incorrect operation of the grounding system with the consequent risk to the safety of people. In the present work, using software developed by the authors, the possibility of replacing copper with other alternative materials is studied. Although they may have a non-negligible internal resistance, this characteristic may not have a significant impact on the electrical parameters of the grounding system as will be shown by studying some typical configurations of grounding electrodes, commonly used in transformation centers installed in buildings.

Keywords: *Alternative Materials, Grounding Electrodes, Internal Resistance, Transformation Centers in Building.*

1. INTRODUCTION

In the design of grounding systems, it is common to use copper as the material of which the electrodes are made [1]. This material is almost a perfect conductor since its resistivity is $\rho = 1.78 \cdot 10^{-8}\Omega$m. In addition, it does not rust easily and is malleable enough to adapt *in situ* to possible irregularities in the ground in the process of placing it on the soil. As for the drawbacks of using such a material, its high cost together with the non-sustainability of its exploitation are the main reasons for exploring other alternative materials with which to design the grounding electrodes. The cost of copper makes it especially attractive to be plundered [2], which can cause the grounding system not to work correctly [3].

The replacement of copper by cheaper materials has been addressed by various authors, although the main concern has focused on oxidation [4]. In particular, some studies carried out with copper-clad steel can be found in the literature [5]. The internal resistance of the conductors makes it necessary to review the well-known Charge Simulated Method (CSM) for calculating the grounding resistance to incorporate a nonequipotential profile of the conductors [6]. As a consequence, the point of injection of the fault current is of great importance to optimize the grounding system.

The substitution of copper for more sustainable materials without significantly altering the essential characteristics of the grounding system in certain types of electrodes will be shown in this paper. To achieve this goal, after this introduction, the following section briefly introduces the model used to incorporate the internal resistance of conductors to the CSM method approach. In the following section the model is applied to several real cases evaluating the modification in the electrode parameters due to the substitution of the material. Finally, in the section dedicated to the conclusions, the results of the calculations are evaluated in order to validate the possible substitution of the material.

2. AN OVERVIEW OF THE THEORETICAL MODEL

The theoretical model on which the calculations are based is a combination of circuit theory and the CSM model. Details can be found in the references [7]-[8]. In the model it is necessary to specify the geometric arrangement of the conductors, their diameter, placement on the ground and the type of material characterized by its resistivity. As for the soil, for simplicity it is considered semi-infinite and homogeneous with known resistivity.

The electrode is fed with fault current at a specified injection point. This current is leaked into the ground through the surface of the conductors. The model calculates the linear current density leaked to the ground at each point of the conductor since the CSM model assumes the thin-wire approximation. In this approximation, each small portion of conductor behaves as a linear distribution of current points. Once the linear current density leaked by the electrode is obtained, it is easy to calculate the potential acquired by it as well as the one generated at any other point on the ground [9].

Using codes written in MatLab, the authors have implemented the method described to calculate the grounding resistance of an electrode as a ratio between the potential acquired by the electrode and the leakage current to the ground. To do this, each rectilinear portion of the electrode is divided into small segments in each of which a constant current is leaked. In the proposed method, a linear system of equations with these currents as unknowns is proposed and solved. The system of linear equations is built from the potentials in each conductor segment, the potentials being linked by circuit laws.

In the next section the model will be applied to the determination of the grounding resistance of various electrodes used in real installations [10]. The calculation will be made for various types of materials, comparing the results with the case of not considering the internal resistance associated with the conductors. As will be seen, the differences can be significant.

3. SOME CASES STUDY

In this paper, the following three typical grounding systems used for building transformation center have been studied.

- **CASE 1: BUILDING TRANSFORMATION CENTER IN INDUSTRIAL AREA**

  Grounding electrode made up of a bare conductor that consist of a ring and four vertical rods at the corners (Figure 1).

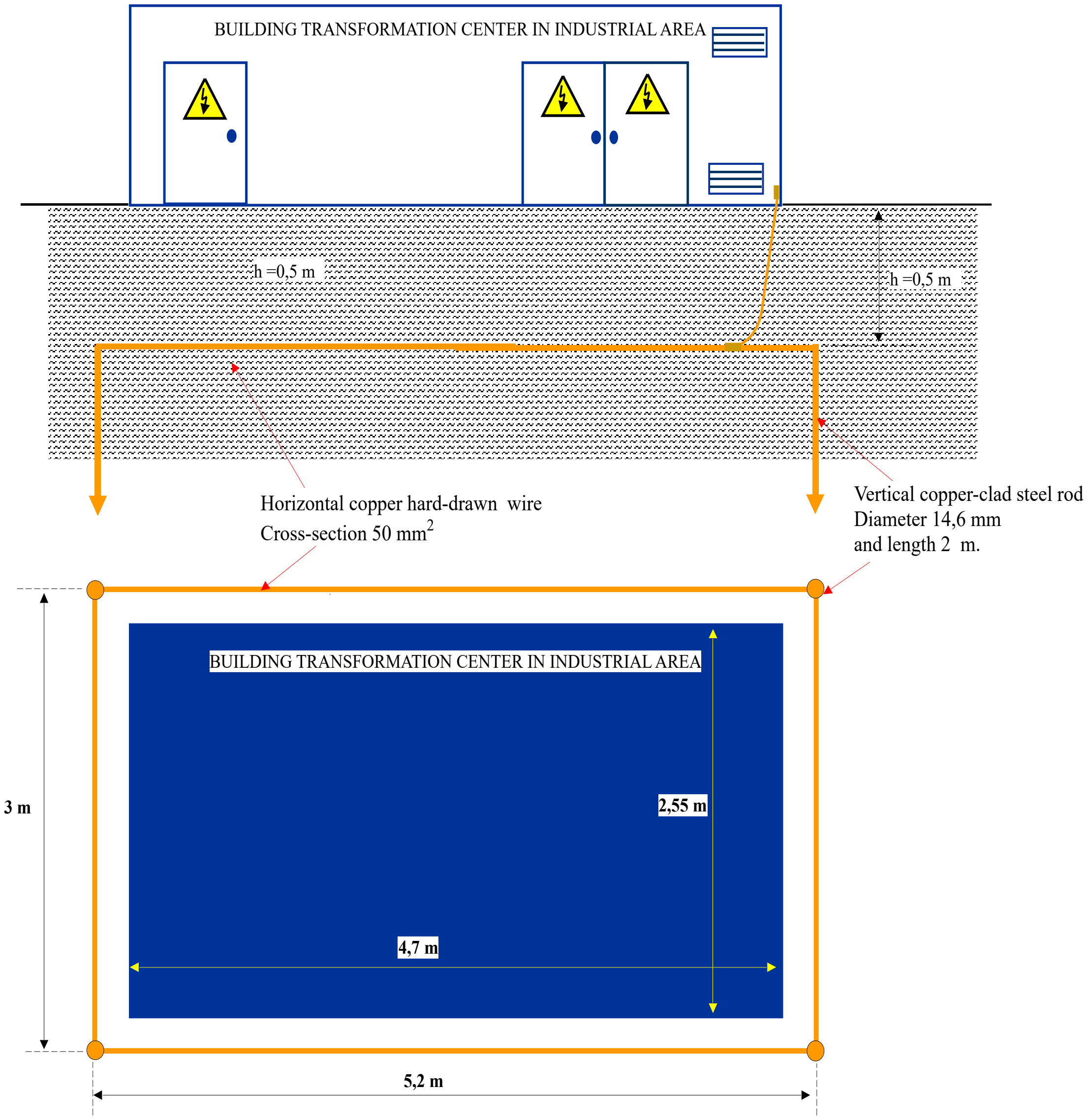

Figure 1: *Example of grounding systems for a Building Transformation Center in industrial area. (Own source)*

- **CASE 2: TRANSFORMATION CENTER IN RESIDENTIAL BUILDING**

  Grounding electrode consisting of a horizontal bare conductor and four vertical rods (Figure 2).

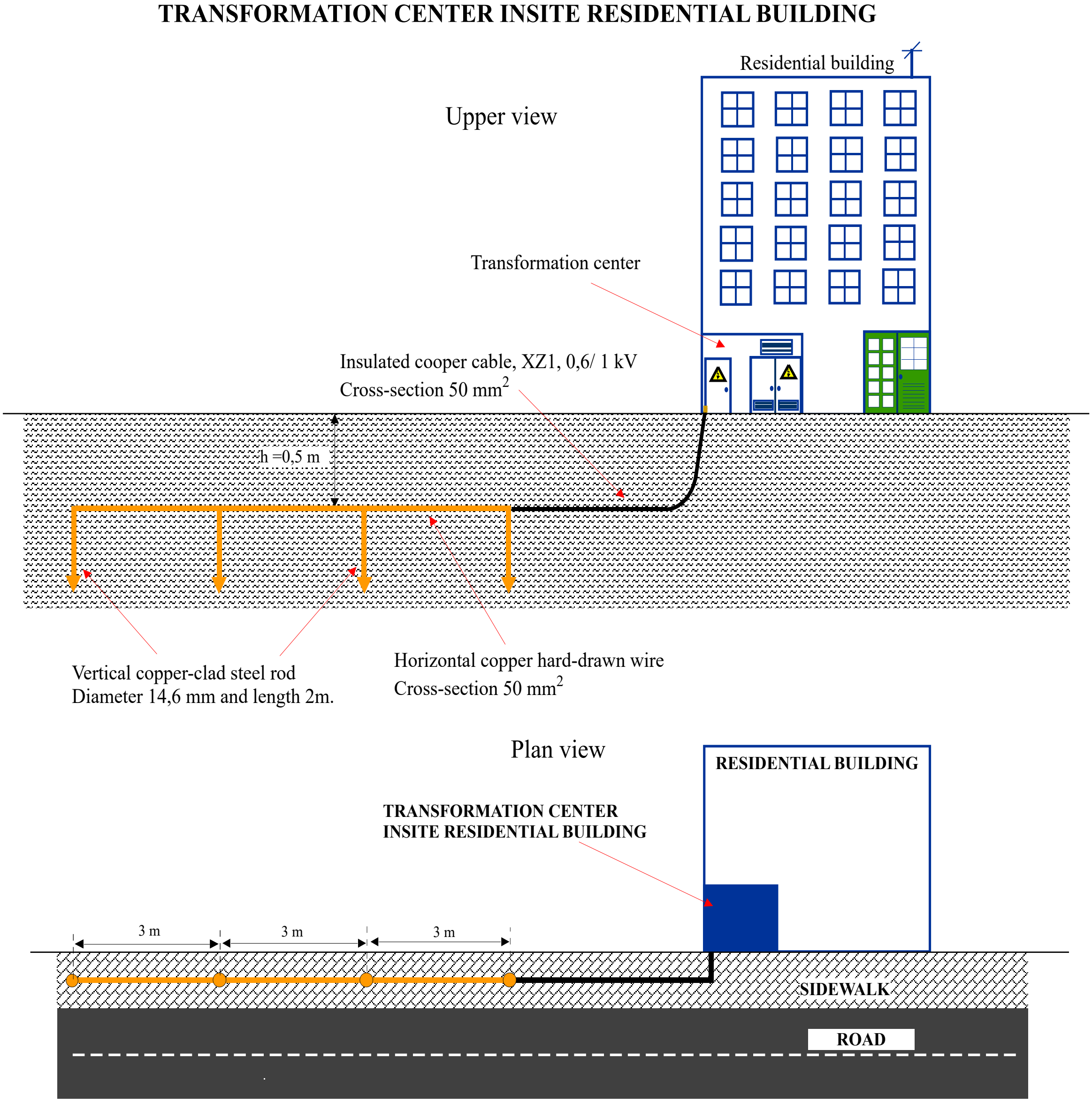

Figure 2: *Example of grounding systems for a Transformation Center inside residential building. (Own source)*

- CASE 3: OUTDOOR TRANSFORMATION CENTER

  Grounding electrode consisting of a horizontal grid made of bare conductors (Figure 3).

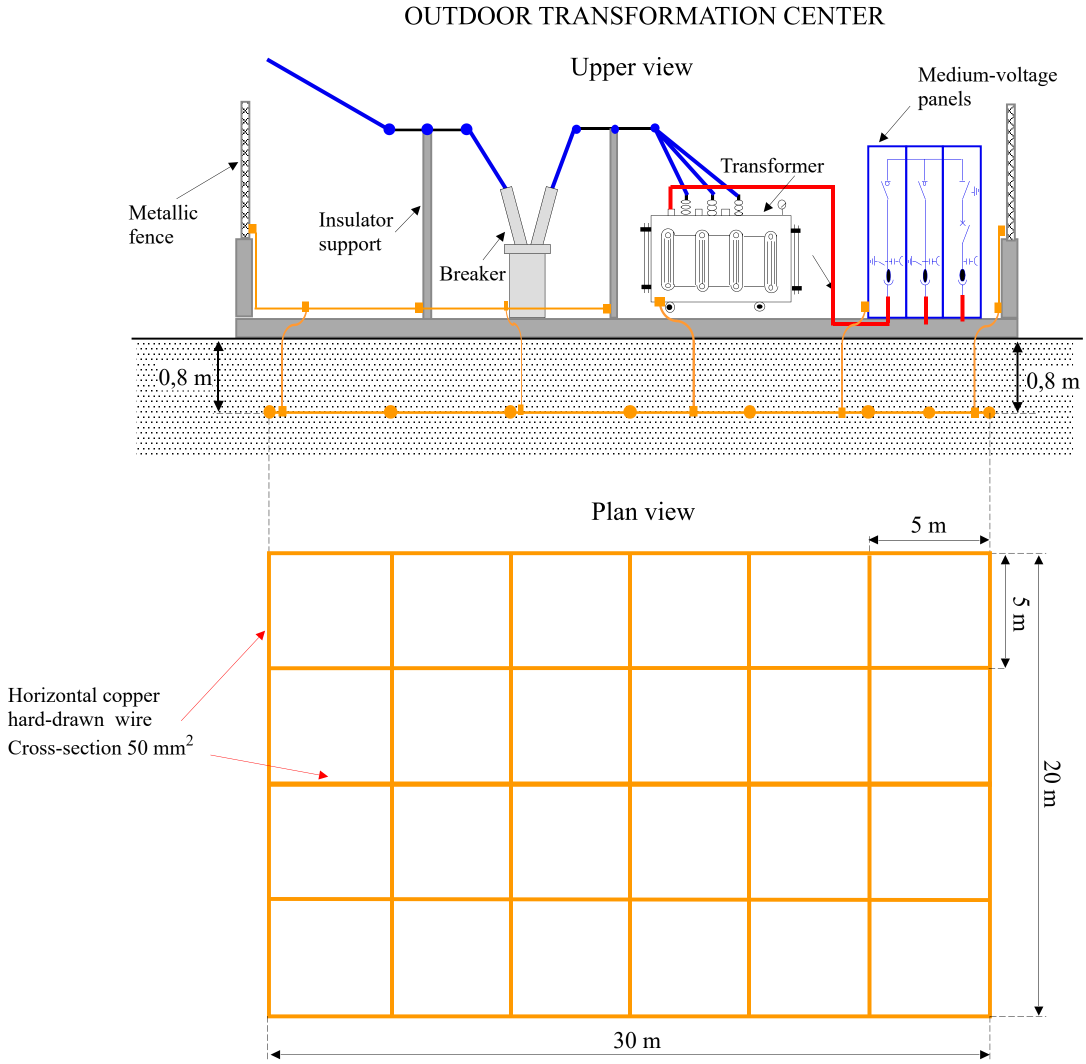

Figure 3: *Example of grounding systems for an Outdoor Transformation. (Own source)*

For the three grounding electrodes described above, the grounding resistance has been calculated by considering two different situations involving different calculation procedures:

1. Disregarding the internal resistance of the electrodes.
2. Considering the internal resistance of the electrodes for different types of materials which electrical resistivity is shown in Table 1.

Table 1: *Electrical Resistivity at 20ºC (source IEEE Std 80TM-2013 [3])*

Type of material	Resistivity (μΩ cm)
Copper, commercial hard-drawn	1.78
Copper-clad steel wire	5.86
Copper-clad steel rod	10.1
Aluminium-clad steel wire	8.48
Steel, 1020	15.90
Stainless-clad steel rod	17.50
Zinc-coated steel rod	20.10
Stainless steel,304	72.00

The calculation results of the electrode grounding resistance when the soil resistivity is set to 100 Ω.m are shown in table 2:

Table 2: *Results of grounding resistance*

Grounding system type	Type of grounding electrode material	Grounding Resistance (Ω)	Error (if the internal resistance of the electrode is not considered) %
Case 1: Building transformation center in industrial area	Internal resistance is not considered.	8.955	0.00%
	Copper hard-drawn ring and 4 vertical copper-clad steel rods.	8.955	0.01%
	The entire electrode made of copper-clad steel.	8.956	0.02%
	Aluminium-clad steel ring and 4 vertical zinc-coated steel rods.	8.957	0.03%
	Stainless steel 304 ring and 4 vertical Stainless-clad steel.	8.973	0.21%
Case 2: Transformation center in residential building	Internal resistance is not considered.	10.329	0.00%
	Horizontal copper hard-drawn wire and 4 vertical copper-clad steel rods.	10.330	0.01%
	The entire electrode made of copper-clad steel.	10.333	0.03%
	Horizontal aluminium-clad steel wire and 4 vertical zinc-coated steel rods.	10.334	0.04%
	Horizontal stainless steel 304 wire and 4 vertical Stainless-clad steel.	10.368	0.37%

Grounding system type	Type of grounding electrode material	Grounding Resistance (Ω)	Error (if the internal resistance of the electrode is not considered) %
Case 3: Outdoor transformation center	Internal resistance is not considered.	1.866	0.00%
	Copper commercial hard-drawn wire	1.868	0.09%
	Copper-clad steel wire	1.872	0.31%
	Aluminium-clad steel wire	1.874	0.44%
	Steel 1020	1.882	0.83%
	Stainless steel 304	1.936	3.75%

For all the cases studied in this paper, it is necessary to highlight the increase in the resistance of the electrode due to the fact of considering the internal resistance of the grounding electrode. This effect is more noticeable the longer the electrode is. For small-sized electrodes such as those discussed in cases 1 and 2, the substitution of copper for other materials can be considered negligible. In return, the cost savings can be interesting and the dissuasive effect for thefts must be taken into account.

As already pointed out above, for large electrodes the substitution of copper by other materials can be critical. In case 3 studied, the substitution of copper for stainless steel 304 the grounding resistance of the electrode by almost 4%. With such an increase, it can be expected that the step and touch potentials may be outside the regulations. This problem can be partially corrected by redesigning the electrode, extending the conductors and increasing their diameter to reduce the grounding resistance. Additionally, the fault current injection point can also be optimized for the reduction of the electrode potential. A comparative study of the involved costs needs to be carried out.

4. CONCLUSIONS

In this work, the effect on the grounding resistance of various types of electrodes, taking into account different types of conductive materials for their manufacture, has been studied. As significant results, for electrodes of small and medium size, the increase in the resistance of the electrode is negligible. On the contrary, for large electrodes, the substitution of copper for another conductive material with higher resistivity produces a increase in grounding resistance if the original geometric characteristics are maintained. Only the modification of the original design together with some other actions, could return to the electrode the values in its electrical parameters that keep it within the margins imposed by current regulations.

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