A Methodology to Calculate Potentials on Buried Electrodes Considering Coupling Between Conductors by the Soil

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This paper presents a practical application of a novel methodology based on an extension of the Average Potential Method to calculate potentials on grounding electrodes considering coupling between conductors by the soil. This problem is of special concern due to the presence of passers-by near metallic fences, whose potentials usually are not evaluated, unintentionally connected to the grounding grid. In this context, the paper presents a study aiming to estimate the possible risk to human beings close to energized grounding conductors, as in the case of the vicinity of a substation. Based on the proposed method, the potentials originating from a short-circuit in the electric power system are calculated considering the coupling between the main grounding grid and the adjacent electrodes.

***Index Terms*—Grounding, high voltage substation, metallic fence, grounding coupled by soil, touch and step potentials.**

I. INTRODUCTION

WHEN the grounding system is submitted to a phase-to-ground short-circuit fault, potentials on the mesh and surrounding area are generated. The coupling through the soil among metallic materials must be considered in the analysis of the Ground Potential Rise (GPR), step and touch voltages and potentials generated on the soil surface. These statements deal with the problem of grounding metallic fences as a property boundary of a high voltage substation (HVS) and its corresponding grounding grid.

In this context, the proposed methodology is focused on the study when the coupling between two or more grounding systems occurs through the soil, *i.e.* a fence outside the substation grounding grid area, but not connected to it.

II. COMPUTATIONAL MODELING

Computational modeling is a reliable alternative to determine with good accuracy the interaction among the conductors that compose a huge grounding system. The involved algorithms should consider: (a) individual modeling of grounding system elements (rods, cables, electrodes); (b) a set of equations that describe the interaction among the various electrodes; (c) the determination of the short-circuit currents that flow from various grounding systems to the soil; and (d) the evaluation of the potential on the soil surface, which can be performed considering a single value of potential at a determined point; a potential profile or a potential surface.

The methodology divides the grounding electrode into segments, where each section has a particular current value. To determine the leakage currents flowing in each segment to the ground, the average electric potential on the surface of each conductor segment is computed and matched to the same value of the constant electrical potential. In addition, the images theory is considered in the formulation.

The algorithm precision depends mainly on the size and the segmentation of each electrode in the mathematical modeling. This definition determines the precision of current densities in each conductor segment. Considering one approach in low frequency, the precision also depends on the medium resistivity and the number of soil layers.

In the proposed study the problem is divided in two parts: the determination of currents injected in the soil by the several elements that compose the grounding system and the determination of the potential at any point of the soil surface.

When the grounding system is formed by N isolated electrodes, the equivalent equations system can be represented by the following generic model,

$$\begin{bmatrix} r^{AA} & r^{AB} & \dots & r^{AN} \\ r^{BA} & r^{BB} & \dots & r^{BN} \\ \dots & \dots & \dots & \dots \\ r^{NA} & r^{NB} & \dots & r^{NN} \end{bmatrix} \cdot \begin{bmatrix} I^{A} \\ I^{B} \\ \dots \\ I^{N} \end{bmatrix} = \begin{bmatrix} U^{A} \\ U^{B} \\ \dots \\ U^{N} \end{bmatrix} \qquad (1)$$

where: R^{XY} is a matrix of mutual resistances between the elements of electrodes X and Y; R^{XX} is a matrix of self resistances and mutual resistances of X electrode elements; I^{X} is a column vector of injected currents in the soil by the elements of electrode X, when the circulation of current to the soil occurs due to a short-circuit in one or more electrodes and U^{N} is a column vector, whose elements are equal to the GPR that occurs in the elements of electrode X.

The solution of the systems of equations (1) can be solved in several ways and the technical choice must consider the entire variable number of the problem. The most appropriate solutions are iterative or direct methods (triangularization or matrix inversion). The fundaments of the formulation is based on [1]-[2] with some improvements to include the coupling by soil among the various electrodes forming the entire system.

III. NUMERICAL EXAMPLE

A system composed of a substation grounding grid with unequally spaced conductors and by a grounded fence not coincident with the potential contours of the substation grounding mesh was used to illustrate the method. Fig. 1 shows both sub-systems: the metallic fence in blue and the substation grounding mesh in black.

The parameters used in the simulation were: soil resistivity of first layer = 120 Ωm; first layer depth = 2.5 m; soil resistivity of second layer = 530 Ωm; substation and fence grounding depth = 0.5 m; substation and fence grounding cable made of copper 70 mm^2; short-circuit current flowing from ground to soil = 1750 A.

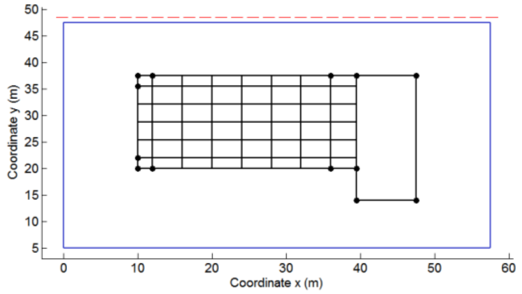

Fig. 1. Layout of the sub-systems: substation grounding and metallic fence grounding.

The current injected in the soil originates only from the substation grounding grid producing a Ground Potential Rise (GPR) in the mesh and also in the grounded fence due to the existing soil coupling. The methodology permits to establish surface and profile potentials allowing for a precise determination of step and touch voltages.

Fig. 2 shows both grounding sub-systems and their corresponding surface potential. Based on this figure the red equipotential curve refers to the potential on the substation grounding mesh and the light blue equipotential curves represent the potential on the fence grounding.

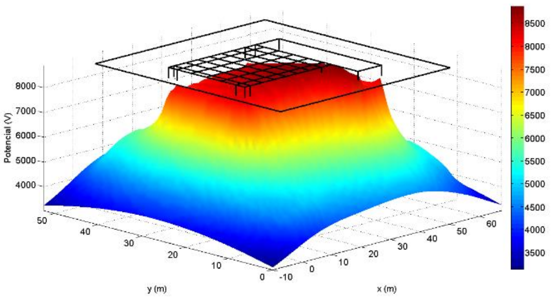

Fig. 2. Surface potential showing the coupling between the substation and fence through the soil.

The GPR in the substation grounding grid is 8874 V with a grounding resistance of 5.07 Ω and the GPR on the fence originating from the coupling by the soil reaches 5119 V. This high value should be very dangerous considering passers-by near the metallic fence in an occurrence of a short-circuit fault in the substation.

In a second analysis, the red dashed line in Fig. 1, which is 1 m away from the substation fence, was evaluated. The potential profile on the soil surface (black line), the substation GPR (red line) and the fence GPR (blue line) are presented in Fig. 3 (top). The produced touch potential on the profile (black line) and the tolerable touch potentials (red and blue lines) are presented in Fig. 3 (middle). The step potential of the studied profile is presented in Fig. 3 (bottom).

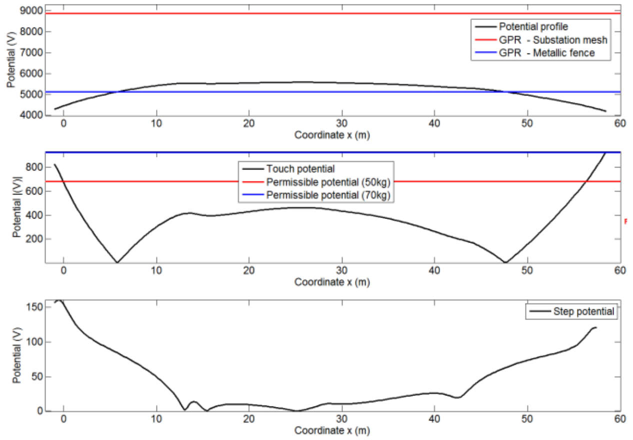

Fig. 3. Profile evaluation. (Top): Potential profile and GPR on the grounding mesh and fence. (Middle): touch potential. (Bottom): step potential.

In Fig. 3 (top), both the substation and the fence GPRs present great magnitude. In some points, the produced touch potential in Fig. 3 (middle) exceeds the tolerable levels established as a safety limit by the standard [3]. According to Fig. 3 (bottom), the step potential does not produce high values of dangerous voltages for human beings. By analyzing the voltages generated near the fence, it is possible to improve the performance of the grounding in order to increase the safety of human beings walking near the substation.

IV. CONCLUSIONS

The methodology presented in this paper permits to determine the coupling through the soil between 2 or more grounding electrodes. The proposed method allows for the evaluation of the step and touch potentials to which passers-by near the metallic fences of a high voltage or extra high voltage substation are exposed to. In this context, some procedures can be adopted in order to ensure the safety of human beings.

The proposed methodology presents a general procedure and can be applied to calculate potentials on buried electrodes for different applications.

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