Electric Power Systems Research 151 (2017) 166–173

Contents lists available at ScienceDirect

Electric Power Systems Research

journal homepage: www.elsevier.com/locate/epsr

Mutual interference of neighboring grounding systems and approximate formulation

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ARTICLE INFO

Article history:
Received 3 December 2015
Received in revised form 8 March 2017
Accepted 23 May 2017
Available online 5 June 2017

Keywords:
Adjacent grounding systems
Mathematical models
Safety risks
Approximate expressions

ABSTRACT

The paper develops mathematical models for the analysis of the mutual interference of closely positioned ground electrodes in order to assess the safety risks that might appear in various circumstances often characteristic for urban areas. The potentially hazardous situation that might arise in open pit mines at the equipment grounded by connection with the common ground electrode is also investigated. In the scope of the analysis of possible dangerous circumstances the maximum touch – and step – voltages that appear at the sites protected by the grounding grids are calculated for various distances between the grids and in case of uniform and nonuniform two – layer soil. Approximate expressions for assessing some interference effects are also provided and successfully checked for various cases. Based upon the results of the conducted series of calculations, the safety risks are determined for all investigated cases. It was shown that the highest safety risks can appear in the case when the neighboring grids are unintentionally connected as well as in the case when the neighboring grid is connected with some grounded objects, which is characteristic for urban areas and for open pit mines with common ground electrodes.

1. Introduction

The complexity of objects consuming electrical energy and their density in space is permanently increasing, which generates new problems concerning the safety of associated persons and equipment and needs for improving the methods for calculation and projecting of grounding systems. In the past, various mathematical models for a detailed analysis of complex grounding systems buried in uniform or two – layer soils have been developed based upon the mean potential concept in calculation of the mutual influences among the conductors of the complex ground electrode [1,2]. The application of the finite element modeling, that increases the computational burden to some extent, has been more recently used for more detailed calculation of various phenomena associated with ground electrodes and neighboring metallic structures linked with or buried in close proximity to them [3–5]. In Ref. [6] the analysis of the mutual influence between the equipment ground electrode on the high voltage side of 10 kV/0.4 kV distribution system transformer stations and the neutral ground electrodes on the low voltage side has been performed. The proximity effects for various spacing of these electrodes when alone and in the presence of neighboring metallic pipes or other conducting structures have been also studied. The finite element modeling has been applied to analyze the potential distribution on the area surrounding ground electrodes as well as the potentials transferred by various metallic conductors buried in close proximity to the grounding area in order to identify possible hazardous situations for persons and equipment [4,7]. This analysis has been conducted both for uniform and two – layer soils. The interference phenomena between grounding systems have been recently detailed considered for assessing the grade of their independency. The matrix calculation method presented in Ref. [8] has been applied to study interactions between the substation grid and the safety ground bed in mining installations [9]. In a recent paper [10], the analysis of the effects of the interference between the ground electrode and fundaments of a transmission line tower and the ground electrode of the adjacent building has been performed and adequate protection measures elaborated. Reference [11] analyzes the effects of neighboring ground electrodes on the distribution of the potentials over an area around the interacting electrodes both in the vicinity of the active and the influenced ground electrode.

This paper analyzes the potentially hazardous circumstances that can appear on the site protected by a grounding grid being in close proximity to another grounding grid dissipating the ground fault current into the surrounding soil. The maximum touch – and step – voltages that appear at the site of the neighboring ground-

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http://dx.doi.org/10.1016/j.epsr.2017.05.029
0378-7796/

ing grid are determined for various distances between the grids in the following characteristic cases that can appear in practice: a) the neighboring grid has no connections with other grounded facilities; b) the considered grounding grids are intentionally or unintentionally linked and c) the neighboring grid is connected to a grounded object. These analyses have been carried out both for uniform and two −layer soils. Approximate, comparatively simple expressions are also derived in the paper for assessing some interference effects and successfully checked for various cases.

2. Mathematical models

2.1. Relationships connecting two neighboring ground electrodes

Let us consider two ground electrodes buried in close proximity. The ground electrodes are composed of sets of interconnected straight line linear elements. It is assumed that ground electrode 1 dissipates current J_1 into the ground due to a ground fault in the installation associated with this electrode. General expression correlating the potentials of the electrodes elements and the currents leaking from them into the surrounding soil has the following form [2,6],

$$[C_1]' \cdot [I_1] = J_1 \quad (1)$$

$$[r_{11}] \cdot [I_1] + [r_{12}] \cdot [I_2] = [C_1] \cdot E_1 \quad (2)$$

$$[r_{21}] \cdot [I_1] + [r_{22}] \cdot [I_2] = [C_2] \cdot E_2 \quad (3)$$

It is implied that the numbers of elements of ground electrodes 1 and 2 are N_1 and N_2, respectively. $[I_1]$ and $[I_2]$ are column vectors of currents dissipating into the ground from the elements of the corresponding ground electrodes, whereas E_1 and E_2 are potentials of these elements. The elements of square matrices $[r_{11}]$ and $[r_{22}]$ are the self- and mutual resistances of the elements of electrodes alone. Elements of matrix $[r_{12}]$ are mutual resistances of the elements of ground electrode 1 with the elements of ground electrode 2. Matrix $[r_{21}]$ is transposed matrix $[r_{12}]$. $[C_1]$ and $[C_2]$ are N_1- and N_2-dimensional column vectors of units and $[C_1]'$ is transposed vector $[C_1]$.

Resistances r_{jk} being elements of resistance matrices in Eqs. (2) and (3) are calculated using the mean potential method. It is implied that the ground electrodes are composed of a set of connected straight-line thin round conductors. Each conductor is replaced by an ellipsoid of revolution with its foci being the ends of the conductor and its smaller axis being equal to the diameter of the conductor. This model of a conductor makes it possible to calculate the potential caused by the current discharging from the conductor at any point in the space using a simple formula based on the distances of this point from the conductor's ends. By applying this expression formed for conductor *j* we can determine the mean potential of any conductor *k* caused by the current discharging from conductor *j*. By dividing this potential by conductor *j* current we obtain the mutual resistance r_{jk} between these two conductors in case when both conductors lie in a discontinues media with the same ground resistivity. For uniform soil the effect of discontinuity at the ground surface is taken by introducing the image of conductor *j* with respect to the ground surface. The potentials of conductor *k* are now calculated by summing the potentials generated by conductor *j* and its image. In the case of two horizontally stratified layers with different resistivities various images of conductor *k* are used depending in which of the layers conductors *k* and j are located. All the details of the calculations both for the uniform and the two-layer soil cases are presented in Ref. [2]. Some of the results obtained by the described calculation method have been successfully checked by modeling in electrolytic tank [6]. A more detailed description of the applied calculation method and a comparison with the exact analytical calculation model presented in Ref. [15] are given in Appendix A.

As can be concluded from expressions (1)–(3), there are $N_1 + N_2$ unknown currents emanating from the elements of ground electrodes as well as unknown potentials of both ground electrodes. These expressions give $N_1 + N_2 + 1$ relationships among the considered variables. The missing relationship, completing the system of equations, depends on the circumstances to be analyzed, as will be discussed further on.

2.2. Electrode 2 is not connected to any other ground electrode

In the case when ground electrode 2 is not connected to any other ground electrode the expression completing the system of equations given before is,

$$J_{c2} = [C_2]' \cdot [I_2] = 0 \quad (4)$$

as current J_{c2} injected into the ground by electrode 2 is null in considered case because the currents from electrode 1 only pass through the elements of electrode 2 with the same total input and output values.

The formed system of equations can be now solved for $[I_1]$, $[I_2]$, E_1 and E_2. The touch – voltages over the site occupied by ground electrode 2 are caused by the difference of the potentials generated by electrode 1 on the ground surface above electrode 2 and the potential E_2.

The potential on the ground surface at a standing point *x* can be calculated using the general expression:

$$E_x = \begin{bmatrix} [r_{1x}] & [r_{2x}] \end{bmatrix} \cdot \begin{bmatrix} [I_1] \\ [I_2] \end{bmatrix} \quad (5)$$

with $[r_{1x}]$ and $[r_{2x}]$ designating N_1- and N_2-dimensional row vectors of mutual resistances of elements of ground electrodes 1 and 2 and the standing point at location *x*.

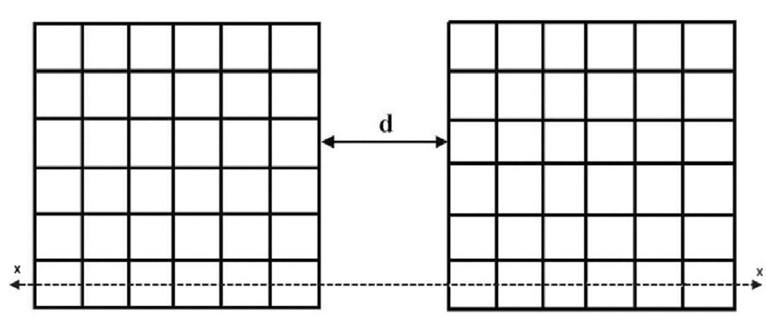

Fig. 1. Grounding grids in close proximity. ----- Route on the ground surface for calculating touch- and step-voltages.