Mesh voltages at earthing grids buried in multi-layer soil

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1. Introduction

The voltage calculated as the potential difference between earthing grid and the standing point at the centre of the grid corner mesh, defined as mesh voltage, is the highest potential difference that can be over bridged by a touch within the substation site. In many cases this is the most critical parameter in earthing system design determining the earthing grid shape and construction. Therefore, the need for relatively simple analytical expressions for calculating mesh voltages was early recognized and some such proposals were made for uniform [1–3] and for two-layer soil cases [4]. However, no attempts were made so far to develop the adequate expressions for mesh voltages in cases with more than two soil layers, which often arise in practice. It was shown by applying various comprehensive mathematical models and software [5–7] that the multi-layer soil structure affects the mesh voltages and that, therefore, it must be properly taken into account. The intention of this paper is to propose relatively simple empirical expressions for evaluating the mesh voltages of typical earth electrodes buried in multi-layer soil to facilitate the design process. The formulae proposed are based on a large number of grid shape and soil stratification cases analyzed by applying the finite elements approach. This is a continuation of the investigations reported in a recent paper [8] related to the resistance to earth of earthing grids in multi-layer soils.

2. Finite-element method application

The grid conductors are modeled by closely spaced equipotential nodal sources. The surrounding soil was modeled by three-dimensional finite elements of various size and shape. For each finite element the following fundamental relationships hold:

\[ \nabla^2 \varphi = 0, \]

\[ \vec{E} = -\nabla \varphi, \]

\[ \vec{J} = \frac{\vec{E}}{\rho}, \]

\[ \varphi = N \varphi_e \]

with \( \varphi \) denoting the potential of any point within the finite element including the points on lateral faces and \( \varphi_e \) being the column vector of potentials of finite element representative nodes. By \( N \) the correlation matrix is denoted depending on the type of finite elements. \( \vec{E} \) and \( \vec{J} \) are the electrical field and current density and \( /\rho/ \) is the resistivity of the soil within the finite element.

The following boundary conditions are valid:

\[ \varphi_e^0 = 100 \text{ V}, \]

\[ \varphi_e^{\text{inf}} = 0 \text{ V}, \]

\[ E_1 = E_2, \]

\[ E_{1n} = E_{2n}, \]

\[ \rho_1 = \rho_2, \]

(2)