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Grounding system impedance characterization using FEM

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Abstract.

The exact knowledge of the grounding system impedance, including its expected variability, is a matter of paramount importance in the design of medium and high voltage infrastructures. The principles underlining the physical processes involved in grounding are well established and so are the engineering concepts regarding safe operation of the grounded systems. Quite a few theoretical expressions are widely used in the project stage of any installation.
Unfortunately, these expressions are only valid for simple geometries and simplified material characteristics. Uncertainty arise from the intrinsic complexity of the grounding environment: buried grids and rods, reinforced concrete foundations surrounding them, weather dependent and non-uniform soil characteristics, etc
To overcome these limitations, in this paper the finite element method is applied to obtain the grounding impedance and the potential distribution around a real grounding system excited with sinusoidal currents at several frequencies.
Additionally, for validating purposes, a single vertical ground rod has been simulated and compared with the results obtained by other authors.
FEM commercial software, in addition to some specific purpose user functions, has been used.
The method presented in this paper can be applied to any real geometry, electrode configuration and type of soil.

Key words

Grounding systems, protection systems, finite element method, soil properties, high frequency.

1. Introduction

The behavior of the grounding system is a key aspect not only for the correct operation of the electrical system but also for the safety of the people living near or working at electrical infrastructures.

The grounding system includes the metallic electrode, defined by its geometrical dimensions and conducting material composition, and the electrolytically conducting ground, mainly soil, defined by resistivity, permittivity and permeability.
Ground system behavior is highly dependent on the electrode geometry, on the input current wave characteristics and on the electromagnetic properties of the ground. Models based on direct (constant) current are static approximations and become useless at high frequencies [1] because eddy current and displacement current are no longer negligible. In addition, al high frequencies, the shrinking wavelength and the grounding system dimensions become comparable [2], thus distributed parameter models are mandatory.
Fig. 1. shows a high-frequency lumped-parameters T-circuit in a single vertical rod electrode where the series circuit represents the resistance of the metallic electrode and the overall inductance, the parallel circuit represents ground resistance and capacitance and the series circuit partition point varies according to the frequency-varying current penetration along the rod. This kind of models can provide a reasonable estimate for the ground impedance and may be used in electric system calculations, but are unable to estimate safety related magnitudes such as touch and step voltage or transferred voltages, much less these models can provide the ground surface potential profile or the current density distribution inside the ground.

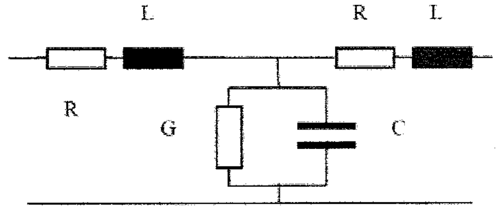

Fig. 1. High-frequency lumped-parameters equivalent circuit for a single vertical ground rod [1].