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# Searching for soil models' parameters using metaheuristics

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ABSTRACT

Grounding systems are an important part of protection systems which protect people and devices in case of defects in electro energetic systems or lightning strikes. The Finite Element Method (FEM) is often used for proper dimensioning of the grounding systems. Often data about the soil in the surroundings of the grounding system are obtained using measurements. Soil parameters can be determined using analytical soil models, and the determination of the soil models' parameters, which are based on the measured data, is an optimization problem. In this paper, different soil models are tested on different measured data and compared with each other. Different metaheuristics are used and tested for the determination of soil parameters: A Genetic Algorithm, Differential Evolution with two different strategies, Teaching-Learning Based Optimization, Artificial Bee Colony and Dynamic Optimization using Self-Adaptive Differential Evolution. Based on the test results, we improved the most appropriate method. As a result, the most appropriate soil model among those tested is selected, and a method for parameter determination is presented which combines Artificial Bee Colony and Teaching-Learning Based Optimization. The presented solution is appropriate to be used with, or as a part of, FEM calculation software.



## 1. Introduction

Grounding systems are an important part of protection systems, which protect people and electric devices in case of defects in electro energetic systems or lightning strikes. It is important that the grounding system is dimensioned properly. For this purpose, numerical analysis, such as the Finite Element Method (FEM), [1–11] is used widely. The effectiveness of the grounding system depends on the geometry and dimensions of the grounding system, and on the characteristics of the soil in which the grounding system is buried.

Grounding systems can be separate systems buried in the soil, or they can be part of a building's foundation. FEM analysis offers the possibility of calculating the electric potential and electric current distribution in the surroundings of the grounding system [12]. Based on that, quantities which are important for safety can be determined, such as electric potential distribution on the ground surface, step voltage and touch voltage. The use of FEM gives us the possibility for effective dimensioning and optimization of a grounding system.

For the FEM analysis of the grounding system, data about the soil are needed in the surroundings of the grounding system. Often this data is not available, but it must be obtained. Different measuring methods are used. One of the most common ones is the Wenner method [13–16], also the Schlumberger method is used in Ref. [16] and in Ref. [13] the Generalized method is mentioned. Using the Wenner four-electrode method, the dependence is obtained of apparent resistivity upon the distance of the electrodes. This set of apparent resistivity versus electrode spacing data is interpreted using inversion methods to find an equivalent horizontally layered soil structure that best fits the measurement data [14].

As mentioned, we are dealing with an inverse problem. In the past, two and multi-layered analytical models were developed horizontally [14–18]. In the literature different works can be found, which present soil parameters' determination using different standard optimization methods [19–21,28–31], and, in the present period, soil parameters' determination also works using modern metaheuristics [17,22–25]. Mainly two and three-layered soil models are in use. In Ref. [19] the Steepest descent method, Levenberg-Marquardt method, Newton method, Generalized Inverse method and Quasi-Newton method are mentioned. A Second-order gradient technique is presented in Ref. [20] and the usage of Electrostatic Images is presented in Ref. [21]. In Ref. [28], the Complex Image Method for estimation of soil parameters was presented by Zhang et al. In Ref. [29], Lagace et al. solved the same problem using the Marquardt method. Zou et al. developed a two-stage algorithm for soil parameters' determination and presented it in Ref. [30]. Kang et al. [31], used nonlinear regres-

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sion for multilayer soil parameters' determination. Calixto et al. [22] used the Quasi-Newton and Complex Imager approaches and compared results with results obtained with a genetic algorithm. Nor et al. [23] solved the soil parameters' determination problem using the compared Master Curves method and a genetic algorithm. Gonos et al. [17] and Zhiqiang et al. [24] used a genetic algorithm for multilayer soil parameters' determination. Differently, in Ref. [25], Pereira decided to use differential evolution for soil parameters' determination.

In the related work [17–25,28–31] authors used standard optimization methods and metaheuristics. Standard optimization methods are faster than metaheuristics. However, for standard optimization methods analytical derivatives must be known, which are not known for the presented problem. The main disadvantage of the standard optimization methods is the fact that they can get stuck in the local minima, which is not the case for metaheuristics. Other authors used only a Genetic Algorithm and Differential Evolution; in our work, we also used Teaching-Learning Based Optimization and Artificial Bee Colony. The presented work shows comparison between different metaheuristics among themselves, and different soil models are tested, with the purpose to get a general approach for the considered problem. In the related work, only partial comparisons are presented, for example, comparison between one standard method and one metaheuristic.

In our work, we tested the two-layered, the simplified two-layered and the three-layered models. The aim of the work was to find which of the tested models is the most appropriate, and to determine the best metaheuristics [26,27] among the tested models for the determination of the soil parameters. Three different sets of measured data were used for the determination of soil parameters.

In real-world applications, soil parameters obtained based on soil models are used in FEM software to design and optimise grounding systems. The procedure for the determination of soil parameters can also be a separate programme and the calculated soil parameters can be used as input data in any FEM software.

The remainder of this paper is organised as follows. In Section 2, the Wenner method is described and three test data sets are presented, together with their descriptions of the soil models. In Section 3, the metaheuristics are presented, with their parameters used for solving the problem. The calculated results for all test examples using three different soil models and six metaheuristics are presented in Section 4. The obtained results are analysed. An improved calculation is presented in Section 5. Finally, in Section 6, conclusions are given considering the soil models and used evolutionary methods.

## 2. The Wenner method, test examples and soil models

### 2.1. The Wenner method

Having adequate information regarding the soil structure is very important in the design of grounding systems. Ground impedance, touch and step voltage and ground potential rise depend a lot on the electric resistivity of the soil. Data obtained from the soil resistivity measurements are interpreted to estimate the electrical resistivity of the soil at different depths. A typical method to measure the resistivity of the soil is the Wenner four-electrode method [13–16]. Measurements using the Wenner method are made according to the Standards IEEE 81–1983 and IEEE 81–2012 [32,33]. In this method, four electrodes are spaced equally along a straight line, as shown in Fig. 1.

A current is forced to flow through the soil between the two outer electrodes, and the voltage difference is measured between the two inner electrodes. As the spacing between the electrodes is increased, the ratio of the measured voltage $U$ to the current $I$ is recorded and gives the resistance $R = U/I$ in ohms. Four auxiliary probes are installed in the earth, all at depth $b$ (Fig. 1) and spaced in a straight line at intervals $d$ (Fig. 1). Then, the apparent resistivity ρ in terms of the length of units in which $d$ and $b$ are measured is defined with Eq. (1) [32].

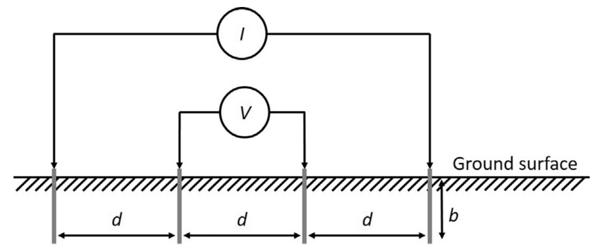


**Fig. 1.** The arrangement of the electrodes in the Wenner method.

$$\rho = \frac{4 \cdot \pi \cdot d \cdot R}{1 + \frac{2 \cdot d}{\sqrt{d^2 + 4 \cdot b^2}} - \frac{d}{\sqrt{d^2 + b^2}}} \quad (1)$$

In practice, four rods are usually driven to a depth not exceeding 0.1 $d$. Then, the user can assume $b = 0$ and Eq. (1) can be rewritten as (2) [15,32].

$$\rho = 2 \cdot \pi \cdot d \cdot R = \frac{2 \cdot \pi \cdot d \cdot U}{I} \quad (2)$$

This set of data containing apparent resistivity versus electrode spacing is used for soil parameters' determination. Data for larger electrode distances contain more information about the resistivity of the deeper soil layers.

### 2.2. Test examples

Three different measured data sets were used for the tests. Test data sets are marked with TE1, TE2 and TE3 and they are written in Table 1.

ρ is apparent resistivity and $d$ is the distance between electrodes, presented in Fig. 1. Test data TE1 is measured data, TE2 was obtained from literature [24] and data TE3 was also obtained from literature [29]. The test data is also presented in Fig. 2. From Fig. 2 it can be seen that we selected three significantly different measured data sets with the aim to make the analysis more general.

### 2.3. Soil models

Horizontally, two or multi-layered analytical models are developed [14–18] to help us find an equivalent horizontally layered soil structure that best fits the measured data obtained using the Wenner method. Soil models, together with some optimization methods, are appropriate for a direct approach to inverse problem calculation. $N$-layered, 2-layered and 3-layered models are shown in Fig. 3.

$h_1$ to $h_N$ are thicknesses of the soil layers, and $\rho_1$ to $\rho_N$ are specific soil resistances of the soil layers. It is assumed that the soil is homogeneous within each layer. We decided to test and compare the 2-layered with the 3-layered model. In the case of the 2-layered model, 3 parameters, $\rho_1$, $h_1$ and $\rho_2$, must be defined, and in the case of the 3-layered model, 5 parameters, $\rho_1$, $h_1$, $\rho_2$, $h_2$ and $\rho_3$, must be defined. The analytic expression for apparent resistance calculation as a function of distance $d$ (presented in Fig. 1) is written in (3) [28].

$$\rho = \rho_1 \left( 1 + 2d \int_0^{\infty} f(\lambda) \left[ J_0(\lambda d) - J_0(2\lambda d) \right] d\lambda \right) \quad (3)$$