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Algorithm for Determining the Parameters of a Two-Layer Soil Model

Adekitan I. Aderibigbe, Fakolujo A. Olaosebikan

Abstract**—**The parameters of a two-layer soil can be determined by processing resistivity data obtained from resistivity measurements carried out on the soil of interest. The processing usually entails applying the resistivity data as inputs to an optimisation function. This paper proposes an algorithm which utilises the square error as an optimisation function. Resistivity data from previous works were applied to test the accuracy of the new algorithm developed and the result obtained conforms significantly to results from previous works.

Keywords**—**Algorithm, earthing, resistivity, two-layer soil-model.

I. Introduction

THE effectiveness of any grounding system is a function of the type of soil in which the grounding system is installed. The major parameter of the soil which directly determines the overall resistance of the grounding system is the resistivity of the soil. The resistivity of a soil is influenced by the moisture content of the soil, the aggregate percentage of the different soil components and the ambient temperature of the soil environment [5].

For safe and effective operation of a grounding system either for the conduction of lightning current or electrical fault current, the resistance of the grounding system must be low, in order to prevent voltage build up along the current flow path which can result in lightning bypass to adjacent objects, the damage of electrical equipment or the risk of electrical shock to people.

Therefore to design a good earthing system, the resistivity profile of the soil in concern must be well known, and this can be obtained by developing a model of the soil using resistivity values obtained from resistivity tests carried out on the soil. In order to achieve a good correlation between the design and the measured earthing system parameters [2], the data obtained from the soil model must be a true representation of the actual soil. This can be achieved by developing a working algorithm which tries to accurately fit the curve of the modelled resistivity values to the measured values.

II. Approaches to Soil Resistivity Measurement

There are different methods of measuring the soil resistivity; the four point method is the most accurate of them all. Two different variations of the four-point method are often used: [1]

A. The Wenner Method [2], [3]

a. Drive four equally spaced electrodes separated by a distance X, from each other into the soil to a maximum depth (Y) of about 5% of distance X.
b. Inject a low frequency current (I) into the current electrodes C1 and C2
c. Measure the earth voltage drop (V) across the two inner voltage electrodes
d. The apparent average resistance of the soil is given by

$$R = \frac{V}{I} \quad (1)$$

The resistivity ρ in ohm metres is

$$\rho = \frac{4\pi x R}{1+\frac{2x}{\sqrt{(x^2+4y^2)}}-\frac{x}{\sqrt{(x^2+y^2)}}} \quad (2)$$

Since **Y** is about 0.1**X** it is assumed = 0. Hence $\rho \approx 2\pi x R$ (Ωm).

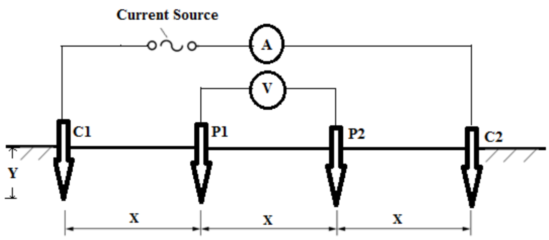

Fig. 1 Electrode setup for the Wenner method

e. Repeat the measurement with increasing values of X to determine the variation of resistivity with increasing depth. An analytical technique may then be applied to compute the resistivity of each layer for a multilayer soil structure or the average value may be assumed as the resistivity of the soil in general.

B. Schlumberger Method [2], [3]

This method comes in handy when there is an obstruction within facilities preventing the use of equal probe spacing or when it is impossible to have all four probes on the same straight traverse line. For large current probe spacing, this approach can be used to ensure that the potential between the two inner potential probes is of sufficient magnitude for easy detection by measuring instruments, by bringing the inner probes closer to the corresponding current probes.

A. I. Adekitan B. Sc.(Hons) UI, GMNSE is a Masters student at the University of Ibadan, Oyo State, Nigeria (phone: +2348038611556; e-mail: ade_kitan@yahoo.com).
A. O. Fakolujo B. Sc.(Hons) Ife, Ph.D. (London), DIC, MNSE, SMIEEE is a Senior Lecturer at the University of Ibadan with the Department of Electrical and Electronic Engineering (e-mail: ao.fakolujo@ui.edu.ng).

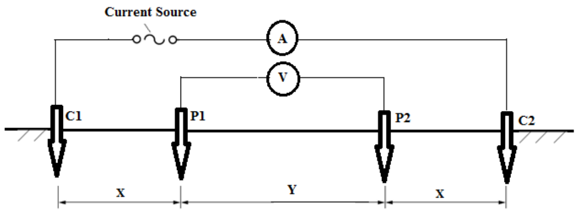

Fig. 2 Electrode setup for the Schlumberger method

a. The apparent average resistance of the soil is given by $R = \frac{V}{I}$

The resistivity ρ in ohm metres= $\frac{X}{Y}(X+Y)\pi R$ (Ωm) (3)

III. Two Layer Soil Model

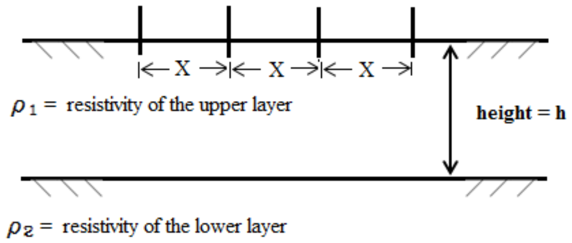

Fig. 3 Two layer soil structure

A two layer soil model for any given soil is said to have been developed when this three parameters are known: the resistivity of the upper layer, the resistivity of the lower layer and the height of the upper layer. To determine these parameters using the developed algorithm, initial values will first of all be assumed, and the best fit for the measured data will be obtained by using measured resistivity data from the soil in concern as inputs into an iterative process.

The algorithm developed by this paper utilizes the square error as an error function in an iterative loop for generating a set of resistivity values which minimises the difference between the measured resistivity values and the calculated apparent resistivity values. This method was proposed by [4] which focused on genetic algorithm.

In the model, value of the height of the upper layer (h) will range between 1 ⃠ h ☛ 6. The program was developed using Visual basic as the GUI interfaced with Matlab as the model generator. For detailed understanding of the algorithm a sound knowledge of arrays as used by Matlab is required. The following formulas are required for developing a soil model.

The apparent resistivity for a given electrode separation x, is given by

$$\rho(x) = \rho_1 \left[1 + 4\sum_{n=1}^{\infty} \frac{k^n}{\sqrt{1+\left(\frac{2nh}{x}\right)^2}} - \frac{k^n}{\sqrt{4+\left(\frac{2nh}{x}\right)^2}}\right] \quad (4)$$

where n = Number of significant terms of the series (e.g. 1-15)

The reflection coefficient:

$$k = \frac{\rho_2 - \rho_1}{\rho_2 + \rho_1} \quad (5)$$

For measured resistivity value $m(i)$, given N numbers of resistivity measurements; for i = 1 to N, let the error function be defined as:

$$\mathrm{EF}\,(\rho 1, \rho 2, \mathrm{h}) = \sum_{i=1}^{N} \left[\frac{m(i) - P(i)}{m(i)}\right]^2 \quad (6)$$

IV. The Algorithm Developed

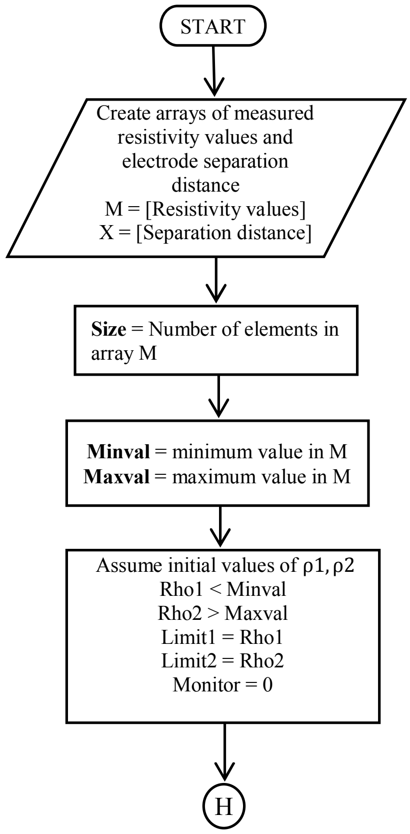

Fig. 4 Data acquisition section of the algorithm

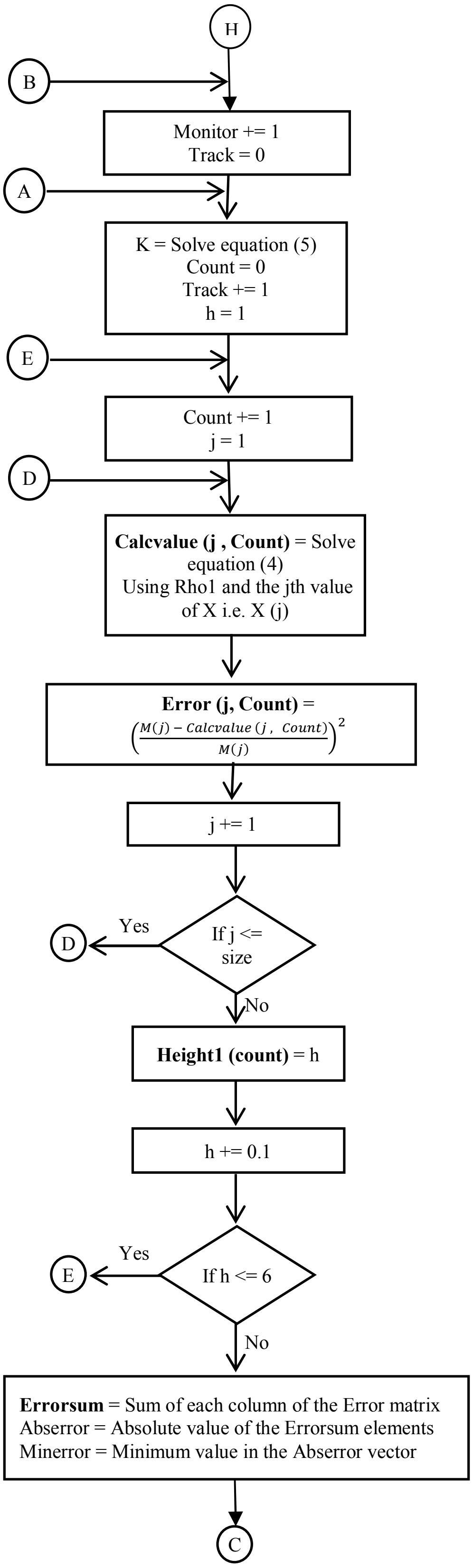

Fig. 5 Resistivity data processing section A

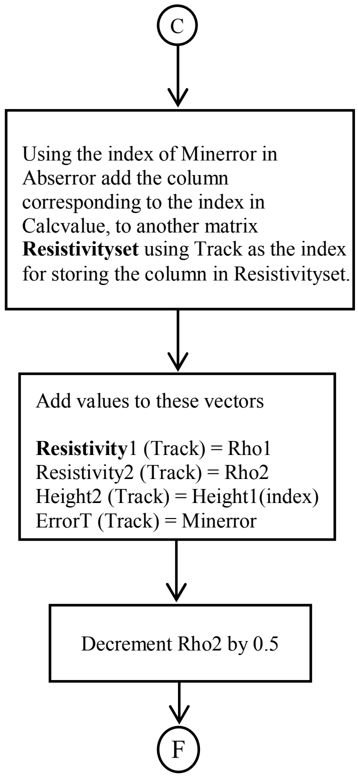

Fig. 6 Resistivity data processing section B

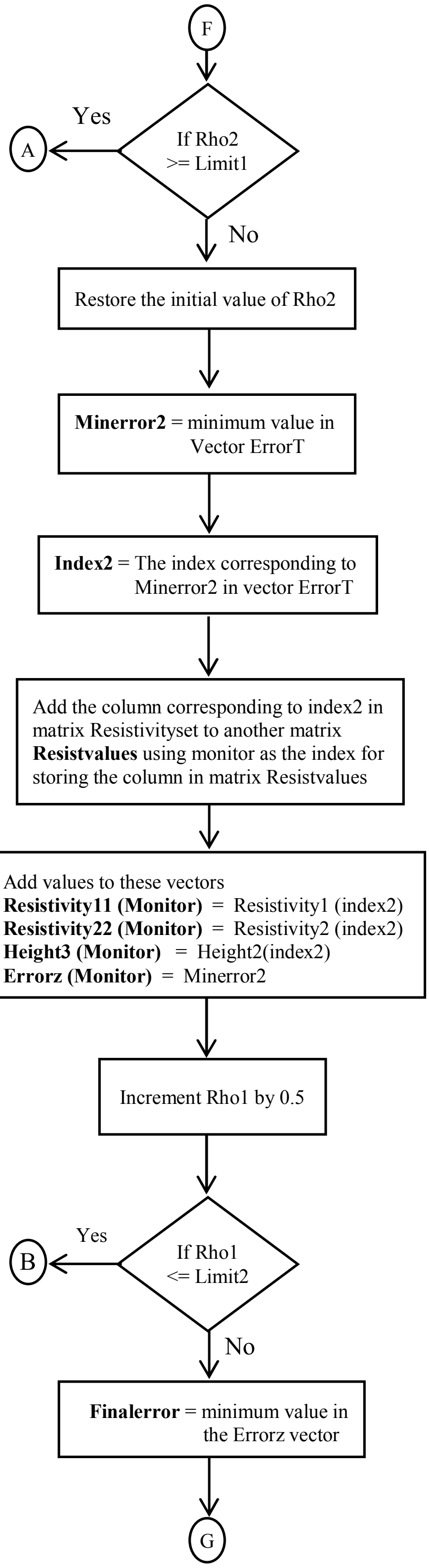

Fig. 7 Algorithm section for evolving the resistivity model

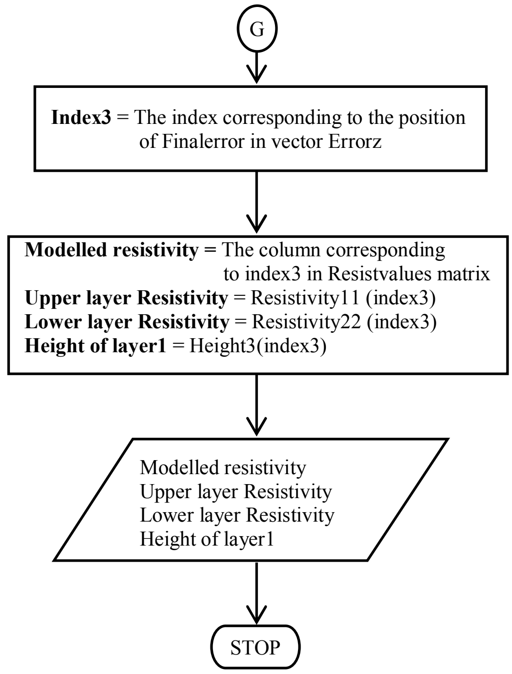

Fig. 8 Output section of the algorithm

V. Results

Using data and experimental results from previous works for direct comparison, Tables I-III have been considered as inputs for the developed algorithm. Tables IV-VI show the result obtained using function F3 (square error) as published by [4] and the result obtained using this algorithm (EF).

TABLE I
EXPERIMENTAL DATA AS PUBLISHED BY [6]

xi [m]	ρ_i [Ωm]	xi [m]	ρ_i [Ωm]
1	693.74	2.5	320
2	251.62	5.0	245
3	84.56	7.5	182
4	37.64	10.0	162
5	25.32	12.5	168
		15.0	152

TABLE II
EXPERIMENTAL DATA AS PUBLISHED BY [2]

xi [m]	ρ_i [Ωm]	xi [m]	ρ_i [Ωm]
2.5	451.6	1	136
5.0	366.7	2	140
7.5	250.2	4	214
10.0	180.0	10	446
12.5	144.2	20	685
15.0	120.2	40	800
20.0	115.5		
25.0	96.5		

TABLE III
EXPERIMENTAL DATA AS PUBLISHED BY [4]

xi [m]	ρ_i [Ωm]	xi [m]	ρ_i [Ωm]
1	87.9	1	40.8
2	62.8	2	40.3
3	56.5	3	38.2
4	37.7	4	32.7
5	29.5	5	26.7
6	26.4	6	24.5
8	17.6	8	20.1
10	15.7	10	17.6

TABLE IV
RESULT COMPARISON (TABLE I)

	F3	EF
ρ1 [Ωm]	900.098	821.064
ρ2 [Ωm]	5.000	5.423
h	1.094	1.100
Error	0.079	0.0493

TABLE V
RESULT COMPARISON (TABLE I)

	F3	EF
ρ1 [Ωm]	360.916	372.500
ρ2 [Ωm]	142.601	145
h	2.875	2.700
Error	0.008	0.0075

TABLE VI
RESULT COMPARISON (TABLE II)

	F3	EF
P1 [Ωm]	492.161	492.250
ρ2 [Ωm]	93.785	93.320
h	4.379	4.400
Error	0.011	0.0111

TABLE VII
RESULT COMPARISON (TABLE II)

	F3	EF
ρ1 [Ωm]	124.957	124.500
ρ2 [Ωm]	1146.874	1133.500
h	2.750	2.700
Error	0.0151	0.0153

TABLE VIII
RESULT COMPARISON (TABLE III)

	F3	EF
ρ1 [Ωm]	84.341	83.640
ρ2 [Ωm]	14.063	13.455
h	2.229	2.300
Error	0.031	0.0298

TABLE IX
RESULT COMPARISON (TABLE III)

	F3	EF
ρ1 [Ωm]	42.186	43.020
ρ2 [Ωm]	13.495	13.660
h	3.289	3.200
Error	0.007	0.0069

Figs. 9–14 are graphs comparing the apparent resistivity values (obtained from the algorithm) with the experimental resistivity values (Tables I-III).

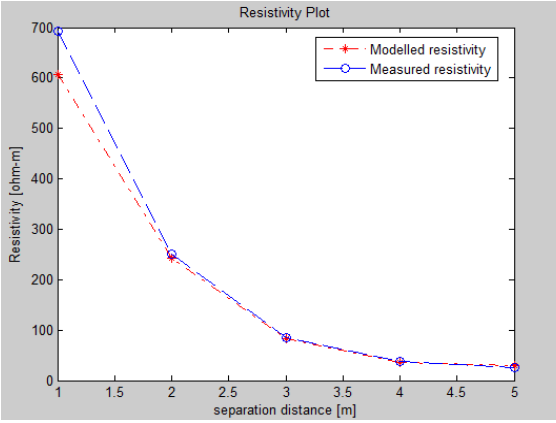

Fig. 9 Comparing the experimental resistivity values of soil with the apparent soil resistivity corresponding to Table IV result

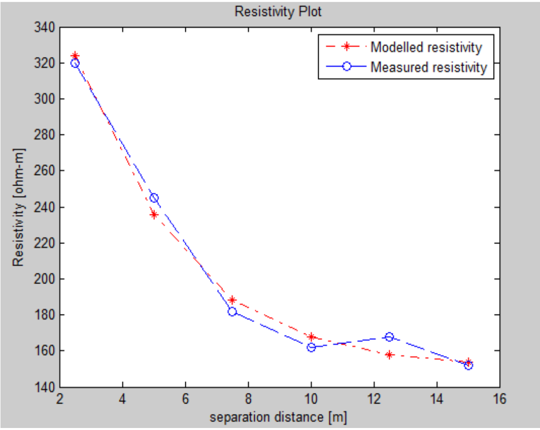

Fig. 10 Comparing the experimental resistivity values of soil with the apparent soil resistivity corresponding to Table V result

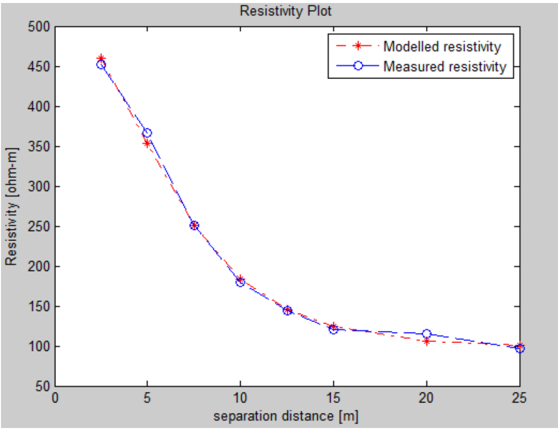

Fig. 11 Comparing the experimental resistivity values of soil with the apparent soil resistivity corresponding to Table VI result

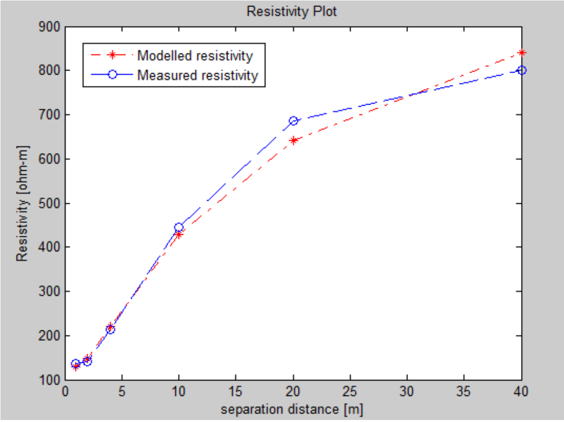

Fig. 12 Comparing the experimental resistivity values of soil with the apparent soil resistivity corresponding to Table VII result

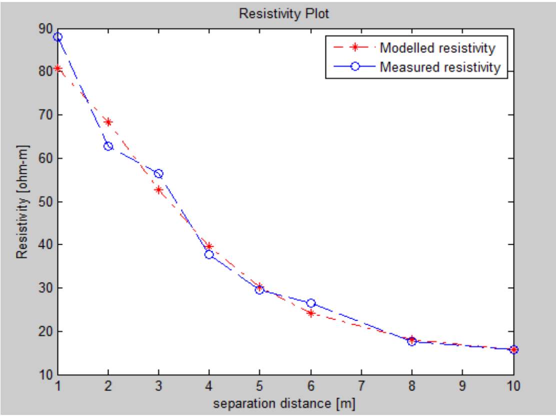

Fig. 13 Comparing the experimental resistivity values of soil with the apparent soil resistivity corresponding to Table VIII result

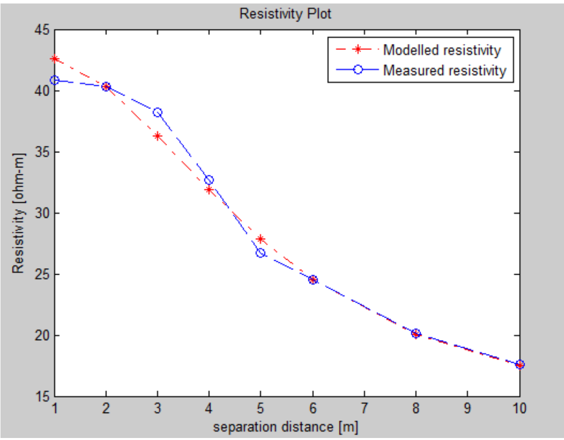

Fig. 14 Comparing the experimental resistivity values of soil with the apparent soil resistivity corresponding to Table IX result

VI. Conclusion

An algorithm for determining the parameters of a two layer soil model has been successfully developed and tested with resistivity data. The result obtained for each set of resistivity data are published in this paper and it shows that this algorithm which utilizes the square error function produces a reasonably accurate result when compared with previous works based on genetic algorithm.

The time taken to determine the two layer soil parameters using this algorithm depends on the range of the resistivity values. For a wide difference between the highest and lowest resistivity value, the time taken may be significantly high, hence there is an opportunity to improve the algorithm by developing a time efficient version.

References

[1] ANSI/IEEE Std 81-1983, “IEEE Guide for measuring Earth Resistivity, Ground Impedance, and Earth Surface Potentials of a Ground System”, 11 March 1983.

[2] Del Alamo J.L.: “A comparison among eight different techniques to achieve an optimum estimation of electrical grounding parameters in two-layered earth”, IEEE Transactions on Power Delivery, Vol. 8, No 4, October 1993, pp. 18901899.

[3] Gary Gilbert, “ High Voltage Grounding Systems”, Doctorate thesis at the department of Electrical and Computer Engineering, University of Waterloo, Waterloo, Ontario, Canada, 2011

[4] Ioannis F. Gonos, Vassiliki T. Kontargyri, Ioannis A. Stathopulos, Antonios X. Moronis, Anastasios P. Sakarellos, Nikolaos I. Kolliopoulos, “Determination of Two Layer Earth Structure Parameters” XVII International Conference on Electromagnetic Disturbances EMD’2007, September 19-21, 2007 Bialystok Poland.

[5] I.T. Dharmadasa, Prof.J. R. Lucas, Dr. L. Udawatta, Eng.W. D. A. S. Wijayapala, “Determination of Earth Resistivity profile in multilayer soil”, Department of Electrical Engineering, University of Moratuwa, Sri Lanka.

[6] Seedher H.R., Arora J.K.: “Estimation of two layer soil parameters using finite Wenner resistivity expressions”, IEEE Transactions on Power Delivery, Vol. 7, No 3, July 1992, pp. 1213-1217.

[7] Rodney Urban, Karl Mardira: “Accurate soil resistivity testing for Power System earthing”, Earthing, Lightning & Surge Protection Forum – IDC Technologies.