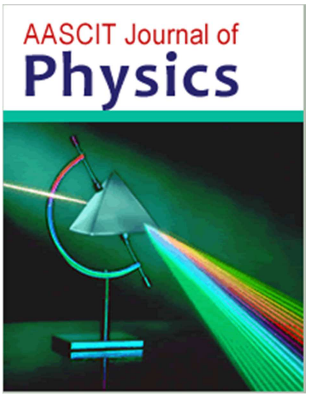
AASCIT Journal of Physics
2015; 1(2): 102-106
Published online May 10, 2015 (http://www.aascit.org/journal/physics)

American Association for Science and Technology



Keywords
Carson Problem,
Multi-Layered Ground,
Dielectric Properties of Ground,
Modified Linear Impedance,
Depth of Penetration

Received: April 15, 2015
Revised: April 24, 2015
Accepted: April 25, 2015

Some Features of Double-Wired Aerial Line's Ground Return Impedance Calculation at Taking into Consideration Multi-Layered Earth's Structure

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Citation
T. Lazimov, E. Saafan. Some Features of Double-Wired Aerial Line's Ground Return Impedance Calculation at Taking into Consideration Multi-Layered Earth's Structure. *AASCIT Journal of Physics.* Vol. 1, No. 2, 2015, pp. 102-106.

Abstract
Some features of calculation ground return impedance of double-wired aerial line passing above the multi-layered ground are considered in the article. The conditions at which the three-layered ground can be presented as homogeneous medium having parameters of the ground's upper layer were determined for the two typical structures of multi-layered ground.

1. Introduction

It is known that mutual impedance of double-wired aerial line (Z_{12}) consist of two parts, the first of which (Z) is determined just by geometrical parameters of the double-wired line (or two single-wired lines) and the second one (Z_{gr}) expresses an influence of ground on propagation of electromagnetic fields along long lines [1].The formula of total mutual impedance of double-wired aerial line is given by;

$$Z_{12} = Z + Z_{gr} \tag{1}$$

The first item in the right side of the formula (1) is an impedance of so called Leher line equaled to the mutual impedance of double-wired aerial line at assumption of superconductivity of ground the line passes over [2].

The second item in the right side of the formula (1) expressed via the Carson integral (see below) determines so called ground return parameters i.e. contribution of the earth into the some parameters of double-wired aerial line such as electrical field intensity [1], magnetic vector potential [3], and mutual impedance of double-wired aerial line [4, 5].The Carson integral for the case of homogeneous ground expressed as;

$$Z_{gr} = R + j\omega L = j\frac{\omega\mu}{\pi}\int_0^\infty \frac{\exp[-(h_m+h_n)\lambda]\cos(a\lambda)}{\lambda+\sqrt{\lambda^2+j\omega\mu\gamma}}\,d\lambda \tag{2}$$

where Z_{gr} is ground return impedance also called modified linear impedance, *Ohm/m*; R is ground return resistance, *Ohm/m*; j is imaginary unit; $\omega=2\pi f$ is angular frequency, *rad/s*, where f is linear frequency, *Hz*; L is ground return inductance, *H/m*; μ is magnetic permeability, *H/m;* h_m and h_n are the mean highs of the two-wired system conductors with indexes m and n, m; a is the projection of distance between these conductors to the horizontal plane, m; γ is conductivity of ground, S/m.

This formula covers just range of frequencies corresponded to the quasi-conductive earth [6]. For the higher frequencies required taking into the consideration longitudinal displacement currents (i.e. taking into the consideration dielectric properties of ground) the Wise formula should be used [7] that expressed as;

$$Z_{gr} = R + j\omega L = j\frac{\omega\mu}{\pi}\int_0^{\infty}\frac{exp[-(h_m+h_n)\lambda]cos(a\lambda)}{\lambda+\sqrt{\lambda^2+j[\omega\mu\gamma+j\omega^2\mu(\varepsilon-\varepsilon_o)]}}d\lambda \quad (3)$$

where ε and ε_o are dielectric permittivity of ground and electric constant of vacuum respectively.

$$Z_{gr} = R + j\omega L = j\frac{\omega\mu}{\pi}\int_0^{\infty}\frac{exp[-(h_m+h_n)\lambda]cos(a\lambda)}{\lambda+\frac{\sqrt{\lambda^2+j[\omega\mu\gamma_1+j\omega^2\mu(\varepsilon_1-\varepsilon_o)]}}{A}}d\lambda \quad (4)$$

The formula (4) has the most common character because of it contains the function (A) called ground impedance that reflected grounds layered structure and parameters. Note that in the formula (4) parameters with subscript *1* concern to the multi-layered ground's upper layer. Ground impedance (A) is determined as;

$$A = coth\left[-jk_1d_1 + coth^{-1}\left[\sqrt{\frac{K_1}{K_2}}\coth\left(-jK_2d_2 + coth^{-1}\sqrt{\frac{K_2}{K_3}}\right)\right]\right], \quad (5)$$

In the formula (5) via d-s are denoted thicknesses of the upper and second layers of the three-layered ground respectively. Via k-s are denoted wave factors of the layers equaled respectively to;

$$k_1 = \sqrt{-(\gamma_1 + j\omega\varepsilon_1)(j\omega\mu_1)}, \quad (6)$$

$$k_2 = \sqrt{-(\gamma_2 + j\omega\varepsilon_2)(j\omega\mu_2)}, \quad (7)$$

$$k_3 = \sqrt{-(\gamma_3 + j\omega\varepsilon_3)(j\omega\mu_3)}. \quad (8)$$

Remind that direct analytical solutions were earlier obtained just for integral (2) in the works [1, 3, and 4], and for integral (3) in the works [6, 7]. Besides in [8] was obtained the principal value of the integral (4), in [9] was proven that this integral does not exist in the terms of general value.

In the next section are presented results of calculation the ground return impedance of double-wired aerial line passing above the three-layered ground for two different cases – with relatively little contrast of layers' electric parameters (sedimentary rocks – granite – basalt structure), and with their greater contrast (fresh water – granite – basalt case). The present research realizes the concept firstly pointed in [10] and based on skin-effect. Calculation were implemented at the fixed thickness of the upper layer d_1 and thicknesses of the second layer d_2= 250, 500, 1000, 2000 meters.

All the results presented below were got for the double-wired aerial line with h_m = h_n= 8 meters and a = 3 meters. Also note that the problem is considered for the case of non-magnetic earth i.e. it is accepted that μ_1=μ_2= μ_3=μ=μ_o, where μ_o is the permeability of free space, H/m. All the computations of the improper integrals (3) and (4) had been done using the MATLAB–2013 set.

2. Results Obtained and Discussion

The calculations carried out showed that the relative difference between mutual impedances in the cases of the three-layered ground and homogeneous ground (with the parameters similar to ones for the upper layer of the three-layered ground) has oscillated character. This also corresponds with results got in [11]. Frequencies at which ground return impedance Z_{gr} of the three-layered ground begins finally to converge with one for the homogeneous ground change between 5 kHz and 20 kHz for the sedimentary rocks – granite – basalt structure, and between 2 kHz and 10 kHz for the fresh water – granite – basalt structure. In accordance with our calculations the relative maximum difference of modified linear impedance conditioned by earth in homogeneity change between 73% and 91% for the sedimentary rocks – granite – basalt structure, and between 104% and 117% for the fresh water – granite – basalt structure. The more relative differences got for the fresh water – granite – basalt case may be explained by greater contrast of the electrical parameters for this case.

The calculations also showed that depths of penetration corresponded to the frequencies at which ground return impedance of the three-layered ground begins finally to converge with one for the homogeneous ground are placed in the second layer of the multi-layered earth.

Below in the Figures 1, 2 are presented calculated graphs of the relative differences of ground return impedances (for three-layered and homogeneous structures) against frequency for the sedimentary rocks – granite – basalt structure (Figure 1), and fresh water – granite – basalt structure (Figure 2). Each of the figures contains four graphs corresponded to the above-minded thicknesses of the second layer at the fixed thickness of the upper layer of 50 meters.

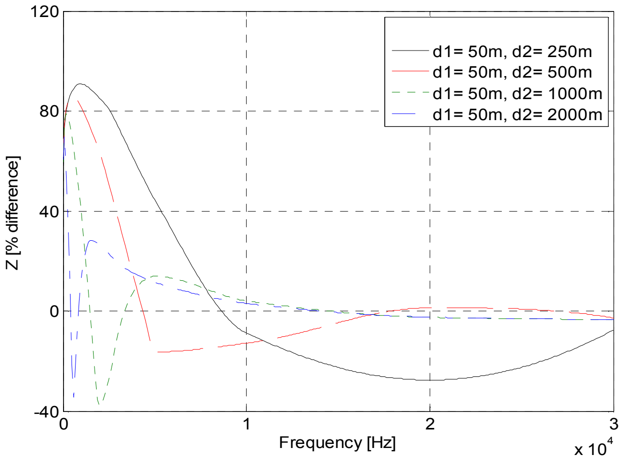


Fig. 1. Relative differences of ground return impedances against frequency for the structure "sedimentary rocks – granite – basalt".

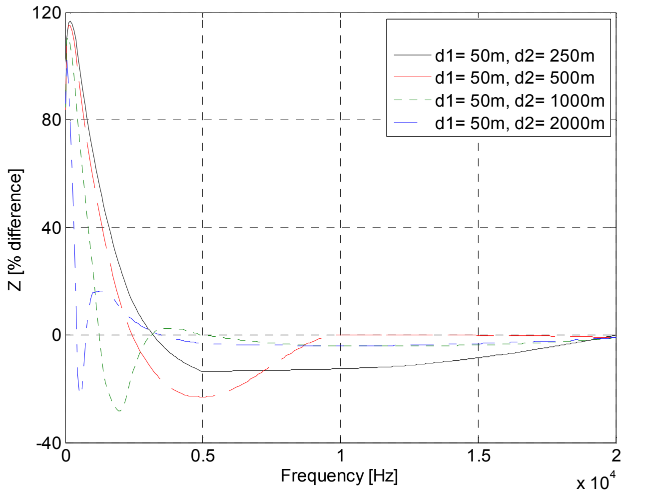


Fig. 2. Relative differences of ground return impedances against frequency for the structure "fresh water– granite – basalt".

The parameters (conductivity and relative permittivity) used in this research are shown in table (1).

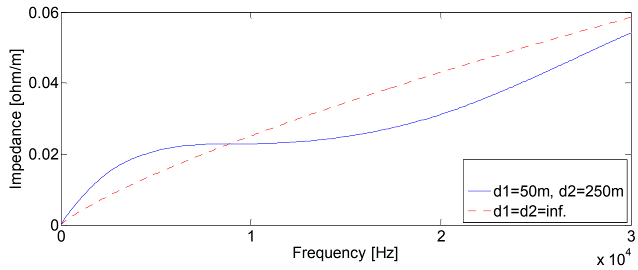
Table (1). Conductivity and relative permittivity of the grounded layers for the cases under study.

type of layer	Conductivity γ, (S/m)	relative permittivity ε_r
fresh water	0.02	80
sedimentary rocks	0.005	5
granite	0.0002	6
basalt	0.0001	7

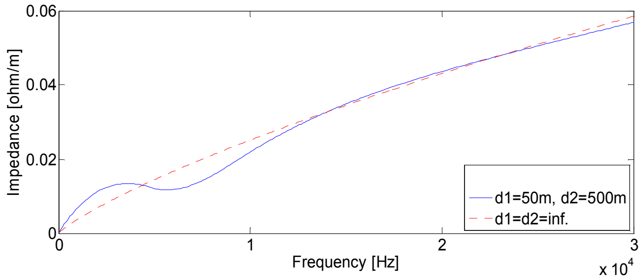
It is evidently seen in the figures 1 and 2 how the ground return impedances' relative differences oscillate and how them finally converge with x-axis. This physically means convergence of ground return impedances of the three-layered ground and homogeneous ground with the parameters similar to ones for the upper layer of the three-layered ground. It is conditioned by intensification of the skin-effect in the earth has taken place at frequency increasing.

In the figures 3 and 4 are presented graphs of calculated ground return impedances against frequency for the three-layered ground in comparison with ones for homogeneous ground having parameters of the upper layer for the two considered structures.

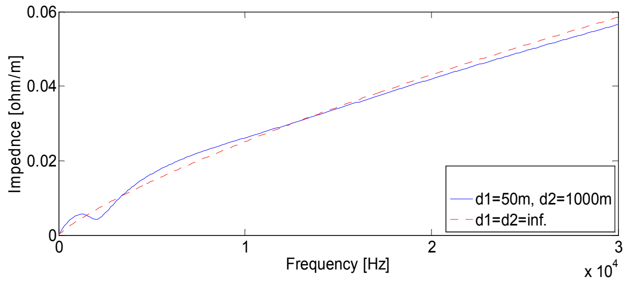
As it was stated in the research increasing of the second layer's thickness at the fixed thickness of the upper layer leads both to some decreasing of the relative differences between impedances of three-layered and homogeneous grounds with the parameters of the upper layer and notable decreasing of the minimum frequency at which the final convergence of the minded impedances has begun.



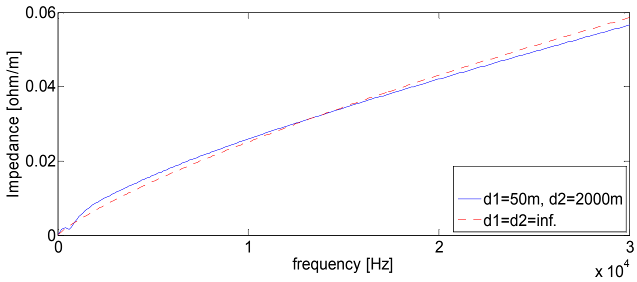
(a)



(b)

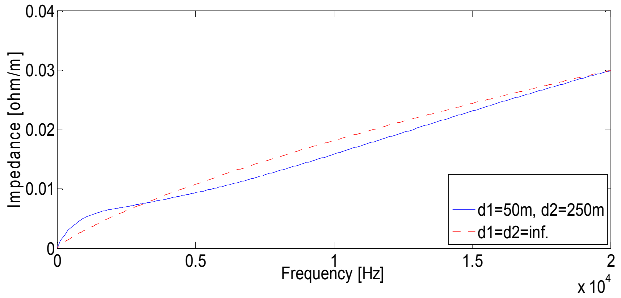


(c)

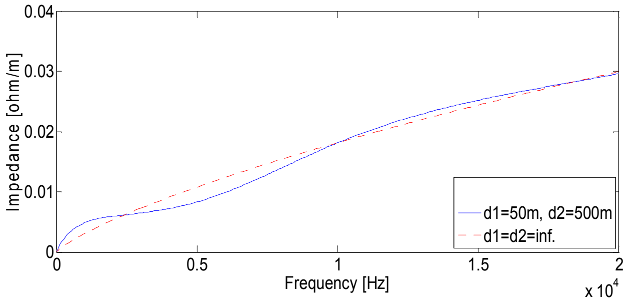


(d)

Fig. 3. Calculated ground return impedances against frequency for the structure "sedimentary rocks – granite – basalt".



(a)



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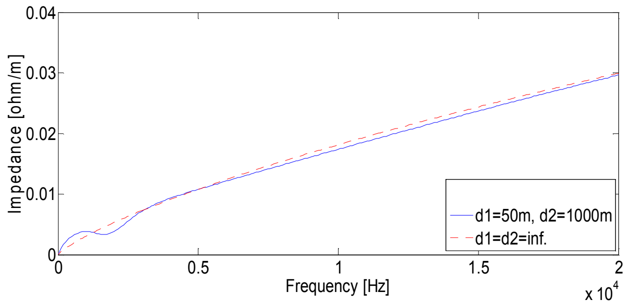

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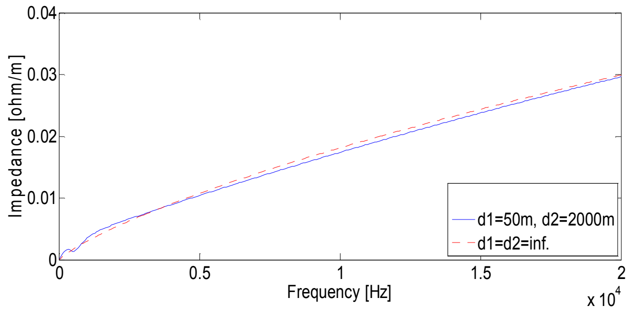

(d)

Fig. 4. *Calculated ground return impedances against frequency for the structure "fresh water – granite – basalt".*

3. Conclusion

It is stated that relative difference between mutual impedances in the cases of the three-layered ground and homogeneous ground with the parameters similar to ones for the upper layer of the three-layered ground has oscillated character.

For the cases with penetration depths calculated in assumption of homogeneity of multi-layered ground (having parameters of the upper layer) less or closed to the thickness of three-layered ground's upper layer have taken place the biggest relative differences between impedances of three-layered and homogeneous ground having parameters of the upper layer.

As a rule penetration depths (δ) corresponded to frequencies at which ground return impedance (Z_{gr}) of the three-layered ground begins finally to converge with one for the homogeneous ground with the parameters of the upper layer are placed in the interval (d_1, d_1+d_2). In rare cases may have taken place at great contrast of layers' parameters the minded penetration depth may be less than upper layer's thickness.

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Biography

Tahir Lazimov was born in Baku, Azerbaijan in 1955. He received the engineer qualification in electrical engineering from the Azerbaijan State Oil Academy, Baku, in 1977, Ph.D. degree in high voltage engineering from the Tomsk Polytechnic Institute, Russia Federation, in 1989. Since 2004 he has been a head of the Electric Supply and Insulation Department in the Azerbaijan Technical University, Baku. He is the author of 170 scientific works. His research areas include transitional processes in power electric systems and their computer simulation, power systems electromagnetic compatibility. Professor T. Lazimov is IEEE Senior member, the member of some academic and editorial boards in Azerbaijan and abroad.

Esam Saafan was born in El-Mansoura, Egypt in 1977. He received the B.Sc. and M.Sc. degrees in Electrical Engineering from Faulty of Engineering, University of El-Mansoura, Egypt in 2001 and 2007 respectively. He obtained the Ph.D. degree in High Voltage Engineering in 2012 from Azerbaijan Technical University, Baku. From 2001 to 2012 he worked in the Electrical Engineering Department, University of El-Mansoura, Egypt as a Lecturer Assistant. Since 2012, he has been a Lecturer in the same university.

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