Scientific Papers of
the Department of Electrical Power Engineering of
the Wrocław University of Technology

PRESENT PROBLEMS OF POWER SYSTEM CONTROL

6

Wrocław 2015

Cover design
Piotr PIERZ

Printed in the camera ready form

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ISSN 2084-2201

Print and binding: beta-druk, www.betadruk.pl

Carson problem, ground return impedance, horizontally-layered earth, penetration depth

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INFLUENCE OF HETEROGENEOUS EARTH LAYERS PARAMETERS' CONTRAST ON GROUND RETURN IMPEDANCE

Aerial electrical line's impedances of ground return through heterogeneous and homogeneous grounds and their differences were calculated for the earth with different interlayer contrast of parameters for series thicknesses of the earth upper layer. Behavior of the impedance differences against changes of frequency and upper layer's depth is investigated in the article. It was shown that the worst approach of relative differences to the zero takes place for the little thicknesses of the earth upper layer (less than 8 meters) and very high frequencies at which the impedance concept loses its certainty and physical meaning.

1. INTRODUCTION

The problem under consideration had been started to be studied in 1926 when John Carson published his known article [1]. In the minded article J. Carson presented a new formula and got it's presentations for argument's little and high bands. The formula expresses earth contribution into some parameters (such as electrical field intensity, magnetic vector potential, ground return parameters [1-4]) of double-wired electrical line passing above homogeneous ground. The Carson formula does not take into consideration dielectric properties of ground. By this reason it cannot be adequate enough for higher frequencies when longitudinal displacement currents cannot be neglected.

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The formula obtained by W. H. Wise [5] is adequate for wider frequency bands because of taking into consideration the dielectric properties of ground via dielectric permittivity appeared in the expression (1) given below. The maximum frequencies provided adequacy at use the Wise formula are estimated in [6]. Note that both Carson and Wise formulae concern just to the cases of homogeneous ground.

$$Z = R + j\omega L = j\frac{\omega\mu}{\pi}\int_0^\infty \frac{e^{[-(h_m+h_n)\lambda]}\cos(a\lambda)}{\lambda + \sqrt{\lambda^2 + j[\omega\mu\gamma + j\omega^2\mu(\varepsilon - \varepsilon_0)]}}d\lambda \tag{1}$$

In the previous formulae Z is so called modified linear impedance, Ohm/m; R is ground return resistance – real component of Z, Ohm/m; j is imaginary unit; ω is electromagnetic field angular frequency, rad/s; determined via linear frequency f as $\omega=2\pi f$, Hz; 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.

A modification of the Wise formula for horizontally-layered ground expressed as following:

$$Z = R + j\omega L = j\frac{\omega\mu}{\pi}\int_0^\infty \frac{e^{[-(h_m+h_n)\lambda]}\cos(a\lambda)}{\lambda + \frac{\sqrt{\lambda^2 + j[\omega\mu\gamma_1 + j\omega^2\mu(\varepsilon_1 - \varepsilon_0)]}}{A}}d\lambda \tag{2}$$

The function *(A)* is so called ground impedance expressed in accordance with [7] as,

$$A = \coth\left[-jk_1 d + \coth^{-1}\sqrt{\frac{K_1}{K_2}}\right] \tag{3}$$

where K_1 and K_2 are the wave factors of the upper and lower layers equaled respectively,

$$K_1 = \sqrt{-(\gamma_1 + j\omega\varepsilon_1)(j\omega\mu_1)} \tag{4}$$

$$K_2 = \sqrt{-(\gamma_2 + j\omega\varepsilon_2)(j\omega\mu_2)} \tag{5}$$

here ε is dielectric permittivity, F/m; $\varepsilon_0=10^{-9}/(36\pi)$ F/m is the dielectric constant, d is thickness of the upper layer, m.

Note here that as it was shown in [8] this integral does not exist in the terms of general value. By this reason numerical calculation of the Carson integral for electrically heterogeneous ground becomes more important.

In some cases for calculation the Carson integral for heterogeneous (horizontally-layered) earth may be used its principal value that was obtained in [7].

2. RESULTS OBTAINED

Let us consider the following two structures of heterogeneous earth strongly differed by layers parameters' contrast. The upper layer for both structures is water with $\gamma_u = 0.02$ S/m; $\varepsilon_{u,r} = 80$; d = 5, 8, 10, 20, 50 and 200 m.

a) For the more contrast case select the parameters of the lower layer $\gamma_l = 0.0001$ S/m, $\varepsilon_{l,r} = 9$ corresponded to granite. For this case the maximum difference between impedance of layered and homogeneous grounds changes between 81 – 160 % in the band of frequencies from 50 Hz to 3 - 5 MHz. Frequencies appropriated to the maximum differences lie in the band 50 Hz – 20 kHz.
b) For the less contrast case select the parameters of the lower layer $\gamma_l = 0.01$ S/m, $\varepsilon_{l,r} = 15$ corresponded to clay. For this case the maximum difference between impedance of layered and homogeneous grounds changes between 48 – 88 % in the band of frequencies from 50 Hz to 3 - 5 MHz. Frequencies appropriated to the maximum differences lie in the band 500 Hz – 1 MHz.

Both cases are illustrated in the fig.1 and fig.2 respectively. There has taken place no good behavior of the relative differences function against frequency at little depths of upper layer (less than 8 meters) for both cases (more and less contrast of the multi-layered ground's parameters). As it is seen from the results obtained the relative differences of impedance become negligible at higher depths for the frequencies in the band 20 kHz - 1 MHz. In contrast, big differences have been occurred at less depth that contradicts with the physical nature of the phenomenon under consideration. We think that this has computational character conditioned by change of physical conditions of electromagnetic waves' propagation.

It is known that the concept of impedance is determined and valid for the plane electromagnetic wave. It is also known that at frequencies about 4 – 5 MHz electromagnetic radiation should not be neglected and the concept of impedance loses its meaning. We think this may explain unusual behavior of relative difference at high frequencies (more than 4 – 5 MHz) for the little thickness of the upper layer. According to formula (6) given below table 1 shows the frequencies appropriated to the penetration depths equaled to the upper layer thicknesses. The frequencies shown are higher (for the little thicknesses of the upper layer) than the valid range mentioned above. As a result, the relative differences of impedance for depths less than 8 meters have a behavior deviated from the expected one.

$$\lambda = \frac{c}{f\sqrt{\varepsilon_{u,r}}}$$

$$d = \lambda$$

$$f = \frac{c}{d\sqrt{\varepsilon_{u,r}}} \tag{5}$$

Table 1. Frequencies corresponded to penetration depths' equaled to the upper layer thickness

λ, m	5	8	10	20	50	200
f, MHz	6.70	4.19	3.35	1.68	0.670	0.168

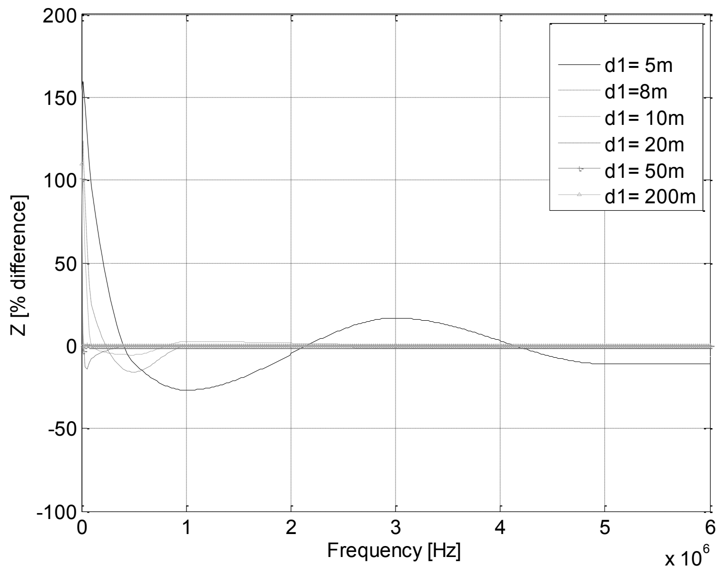

Fig. 1. Relative differences of impedance for the more contrast case

It is known that the electrical nature of substance may be evaluated by comparison of active conductivity γ and capacitive conductivity $(\omega\varepsilon)$. Dependently on relation between these parameters (>>, >, < or <<) a substance may be classified as conductor, bad conductor, bad dielectric and dielectric respectively [9].

For the contrast estimation between layers parameters for both cases use comparison of upper and lower layers conductivities (active and reactive). By using the ratio $\gamma/(\omega\varepsilon)$ to estimate the interlayer contrast for the cases under consideration, the ratio estimated is expressed as $(\gamma_u\ \varepsilon_l)/(\gamma_l\ \varepsilon_u)$. Thus for the more and less contrast cases we get the ratios of interlayer contrast equaled to 22.5 and 0.375 respectively. It means that contrast between the cases considered equals 22.5/0.375 = 60.

Note that as it is seen from the fig. 1 and fig. 2 greater thicknesses of the earth upper layer are characterized with better approach of the relative differences curves to zero. We explain this with relative decreasing of the penetration depth in comparison with upper layer thickness.

The results obtained are well-corresponded to other ones got in our previous researches of the problem under consideration given in [10, 11].

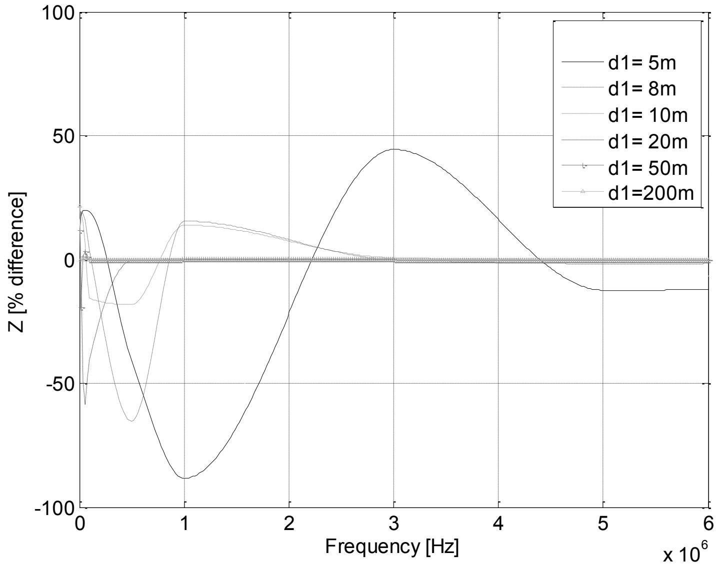

Fig. 2. Relative differences of impedance for the less contrast case

3. CONCLUSIONS

Interlayer contrast of heterogeneous earth parameters influences on difference between ground return impedances calculated for homogeneous and heterogeneous (two-layered for the considered problem) earth. The degree of this influence is rather weak because that increasing the contrast in the dozens of times leads to a change in the minded difference in tens of percent.

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