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IMPULSE IMPEDANCE OF A LONG LINEAR GROUND IN NON LINEAR SOIL

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ABSTRACT
What is presented in this work is the influence of a specific soil resistance as well as the influence of soil nonlinearity on a response of a long linear ground to impulse inputs. Current deployment along the ground is shown and the results of the impulse impedance estimate are presented. Possible errors in case of nonlinearity disregarding are also highlighted.
Keywords: Impulse impedance, non linear soil, linear ground

1. INTRODUCTION
Ground response to impulse inputs differs significantly from the response of direct current stationary states inputs and industrial frequency current inputs. Impulse impedance can be lower or higher than transient resistance of stationary state depending on the slope and the entry impulse intensity. In practice, impulse coefficient is used to show this.
Apart from the mentioned factors, impulse impedance is also influenced by nonlinearity of the ground environment. In this work, the influence of environment nonlinearity on ground response in impulse regimes is analysed.

2. CURRENT DEPLOYMENT ON THE GROUND
There are different approaches in impulse impedance estimates for long linear horizontal grounds in lenear environments [1,2,4].
In nonlinear environments electric field intensity is given in the following relation

$$E = A \cdot J^{\beta} \tag{1}$$

where A - coefficient of variation and β – nonlinearity coefficient.
In linear soils $A=\rho$ and $\beta=1$.
In [2 and 5] the deployment of impulse current along a long ground is analysed and what we have is a simple relation for current deployment (2):

$$i(x,t) = \frac{at}{\ell} + aL\ell g\left(\frac{1}{3} - \frac{x}{\ell} + \frac{x^2}{2\ell^2}\right) \tag{2}$$

where α – slope of input impulse head, ℓ – length of the ground, L – inductivity and g – ground conductivity.
The current expression (2) can be used for calculating impulse impedances in nonlinear environments.The method of iterative apporoaching can be applied. As a zero iteration we can take the absence of nonlinear processes in the soil, according to which the current deployment along the ground is calculated. Based on this deployment, we get the fictitious radius of spark zone and nonlinearity zone. As the first iteration for nonlinear radius, at the spot of current entry on the ground, the impulse impedance is determined.

3. IMPULSE IMPEDANCE ESTIMATE

With the help of relation (2), using calcuated parameters we can decide on the length of the ground x, where the current $i(x,t)$ equals zero. Then, the quadratic equation (2) is solved where one solution is not possible because x>l. So, by solving the equation we find that

$$x = \ell - \ell\sqrt{1 - 2\left(\frac{1}{3} + \frac{t}{gL\ell^2}\right)} \qquad (3)$$

In case that the expression under the square root is lower than zero (unreal solution) we can note that $x = \ell$.

Then, the mean current value is calculated from the peak value (x = 0) to zero, for x from (3). Based on the mean current value, we check if, for the given length, there is sparkover on the ground. If there is, the mean value of spark zone radius r_{fn} is calculated.

The nonlinearity zone radius r_p and the mean value of nonlinear specific resistance ρ_n, but for $\ell = x$.

The calculated ρ_n is inserted in expressions for g, L, C, v, δ, τ and ω_k from (4) where instead of the ground radius r_0, r_{fn} is inserted if there is sparkover.

For values calculated this way and for $\ell = x$, the impuls impedance is calculated using relation (4), given in [5] , i.e.

$$Z(0,t) = \frac{1}{g\ell} - \frac{C}{g^2\ell t}\left(1 - e^{-2\delta t}\right) + \frac{2Lv^2}{\ell t}\cdot\sum_{k=1}^{\infty}\frac{1}{\delta^2 + \omega_k^2}\left[1 - e^{-\delta t}\left(\cos\omega_k t + \frac{\delta}{\omega_k}\sin\omega_k t\right)\right] \qquad (4)$$

where:

$\omega_k = \sqrt{\left(\frac{k\pi}{\tau}\right)^2 - \delta^2}$ - angular frequency of Fourier‘s order

$\tau = \ell\sqrt{LC}\,[\mu s]$ - time during which a wave passes distance ℓ

$\delta = \frac{g}{2C} = \frac{1}{2\varepsilon_r\,\varepsilon_0\,\rho}$ - jamming coefficient

$\sigma = -\frac{g}{2C} = -\frac{1}{2\varepsilon_r\,\varepsilon_0\,\rho}$ - distortion coefficient.

In case that the root value for angular frequencies of Fourier‘s order is negative, and this happens with soils of very good conductivity, then, for the sake of more accurate estimate, expression (5) given in [5] is used, i.e.

$$Z(0,t) = \frac{u(0,t)}{i(0,t)} = \frac{u(0,t)}{at} = \frac{1}{g\ell}\left[1 + \frac{2T_1}{t}\sum_{k=1}^{\infty}\frac{1}{k^2}\left(1 - e^{-\frac{t}{T_k}}\right)\right], \qquad (5)$$

where $T_k = \frac{Lg\ell^2}{k^2\pi^2} = \frac{L\ell}{k^2\pi^2 R} = \frac{T_1}{k^2}$; $T_1, T_2, \cdots, T_k -$ time constants which determine the length of a transient process.

If

$$R = \frac{\rho}{2\pi\ell}\log\frac{\ell^2}{2\pi r_0}, \qquad (6)$$

is transient resestance for stationary state [4], then impulse coefficient is

$$\alpha_i = \frac{Z(0,t)}{R}. \qquad (7)$$

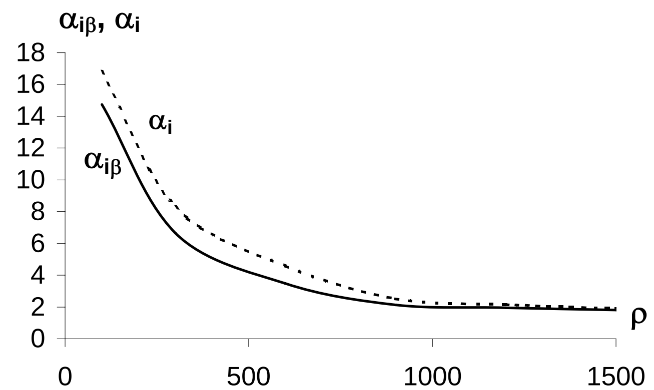
In *Mathad 2001 Professional* program package there is a program designed to calculate impulse impedance i.e. impulse coefficient for soils with different specific resistance in linear and nonlinear environments. This program is based on above-mentioned procedures and relations. Here, we have an estimate for input current of 30 [kA], of standard impulse form for a long circular ground, 1cm

diameter, placed 0.8 [m] deep in the soil.
Calculated values for impulse impedances and impulse coefficients with different values of ρ (100, 300, 600, 900, 1200, 1500, 3000, 6000, 9000 and 12000 Ωm), and for nonlinearity coefficients β which, depending on specific resistance, vary from 0,33 to 1, are given in the grids and pictures. Also, the errors occurring when nonlinearity is disregarded are calculated. In grid 1, there are calculations for impulse coefficients values for nonlinear and linear environment with specific resistance for 100 [m] long ground. Because of the big ground length, it can be noted that the impulse coefficient calculated for nonlinear environment is lower than the same coefficient for linear environment, so that the impulse impedance is small as well, except for high specific resistance values when these two values are the same.

Grid 1

$\alpha_{i\beta}$	14.75	6.665	3.48	2.125	1.957	1.818	1.242	0.834	0.633	0.518
α_i	16.808	8.314	4.588	2.517	2.162	1.92	1.302	0.837	0.633	0.518
ρ [Ωm]	100	300	600	900	1200	1500	3000	6000	9000	12000

In p.1 the impulse coefficient dependance α_i , calculated for linear environment and coefficient $\alpha_{i\beta}$, calculated for nonlinear environment is shown. In order to note the difference between these two values, in the picture the ρ value is given up to 1500 [Ωm]. Beyond this value the two curves come closer anf eventually the values in linear environment of a high specific resistance become equal.



Picture 1. Impulse coefficients of a long linear ground, 100 [m] long, in relation with specific resistance

In grid 2 deviations i.e. errors made if nonlinearity of the environment is disregarded and calculation is done for linear environment, are presented. As a reference i.e. the precise value, the impulse impedance in nonlinear environment is taken, i.e. corresponding impulse coefficient i.e.

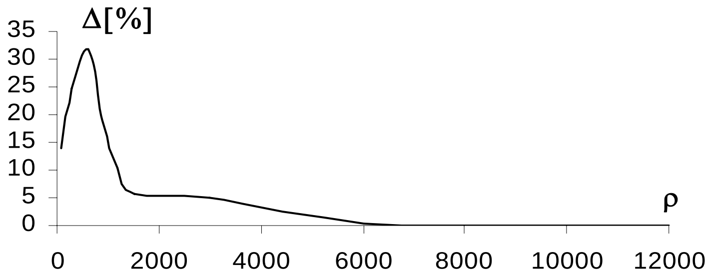
$$\Delta[\%] = \frac{\alpha_i - \alpha_{i\beta}}{\alpha_{i\beta}} \cdot 100 \qquad (8)$$

Grid 2

Δ [%]	13.95	24.74	31.84	18.45	10.48	5.61	4.83	0.36	0.00	0.00
ρ [Ωm]	100	300	600	900	1200	1500	3000	6000	9000	12000

According to grid 2 and picture 2, it can be noted that the deviations for given parameters are positive, i.e. the impulse impedance calculated for linear environment is higher, for given percentages. The biggest deviation is for approximately ρ = 600 [Ωm] and given entry parameters, and it is about

31[%]. For ρ values bigger than 6000 the deviations equal zero, and in that case impulse impedances values i.e. impulse coefficients values match.



Picture 2. Errors because of disregarding the nonlinearity of a linear ground in relation with ρ, for ℓ = 100[m]

In the same way, calculations are done for grounds of different lenghts and other features which are the same as in the above-mentioned case. In [5] an analyses has been done for grounds $\ell = 70[m]$, $\ell = 40[m]$, and $\ell = 10[m]$. The conclusions are similar, except that the deviations i.e. errors are more distinct. The errors could be above 100%.
According to these analyses it can be noted that the influence of the environment nonlinearity around a ground is bigger for the grounds of smaller sizes.

4. CONCLUSION

Taking the above analyses into account, we can come to the conclusion that significant deviations can be made with impulse states on a ground when calculating impulse impedances if soil nonlinearity is disregarded, and that is very common in grounding estimates. The aim of this work is to try and highlight the errors made that way. Depending on expected entry impulse intensities, as well as on the spot where the ground is placed, and using this procedure, we can decide on its length more accurately and very often reduce financial investments in the grounding structure. In case of soils of lower specific resistance the errors can be higher than 100[%], so that the ground may be shorten significantly as well as the investments. For soils whose specific resistance is higher than 5000 [Ωm], practically, there are no deviations from calculations for impulse resistance values in linear environments so that in these cases investment cut-downs in grounding structures cannot be expected.

5. REFFERENCES

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