Two-layer Grounding Grids Using Computational Procedures

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ABSTRACT: *In the work we have developed a system to record two-layer soil structure by calculating the mesh voltage Em. We have used the computational procedure of the standard IEEE 80-000. We have used the formula for homogeneous structure soil with horizontal stratified medium. We have also used a formulae of equivalent resistivity. We have arrived at the Em values based on regular shape of grounding grids.*

Keywords: Grounding, Ground Grid, Mesh Voltage, Two-layer soil

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1. Introduction

Standard IEEE Std 80-2000 [1], being a guide for the design of grounding system of electrical substations, uses the tolerable step and touch voltage depending on the duration of shock current as a criterion for assessment of the efficiency of safe grounding. In the standard, “Mesh voltage E_m” is the maximum touch voltage within a mesh of a ground grid. That voltage E_m must be less than the tolerable touch voltage E_{touch}, defined according to [1].

The standard introduces a coefficient K that takes into account the two-layer structure of the soil:

$$K = \frac{\rho_2 - \rho_1}{\rho_2 + \rho_1} \tag{1}$$

ρ1, ρ2 - soil resistivity of the upper and the lower layer.

The annex *F* of [1] gives a brief discussion of how the different parameters affect the behavior of grounding systems for uniform soil resistivity and for a two-layer soil resistivity. The thickness of the upper layer (h_1) and *K* can have considerable influence on the performance of the ground system [1], i.e. the calculated ground grid resistance may be higher or lower than the same grid in a uniform soil.

The paper [5] shows the potential around the single end group grounding system for a two-layer soil, but there is no formula to calculate the influence of the kind of soil over the resistance of grounding system. There are no results for grid grounding system, either.

The paper [2] extends an electromagnetic model for a timeharmonic analysis of a grounding system to a horizontally stratified multilayer medium which consists of air and arbitrary number of soil layers. The model is based on applying the finite element approach to an integral equation formulation.

Expressions for the mesh voltages [3] caused by earth fault currents leaking from earthing grids buried in uniform, twoand three-layer soils are proposed based upon the examination of a large set of grids and soil structures using the finite element approach. Simple empirical correction factors are developed to modify the mesh voltage formulae for uniform soils so as to account for multi-layer soil structures. The authors suggest a new method for calculation of E_m in multilayer soils, different from IEEE Std 80-2000 method.

The idea of this paper is to propose a simplified method of accounting for a two-layer soil structure based on the value of the mesh voltage E_m in applying the computational procedure of the standard [1]and determining the equivalent resistivity of the soil, given in [2].

2. Mesh Voltage

The equation for mesh voltage [1] is:

$$E_m = \frac{\rho.K_m.K_i.I_G}{L_m} = K_G.I_G \tag{2}$$

I_G – ground fault current, A;

K_G, *V/A*

K_m, K_i, L_m- according to equations (81) to (91) from [1];

ρ - Soil resistivity, Ω*m*.

K_m - Spacing factor for mesh voltage, simplified method

K_i - Correction factor for grid geometry, simplified method

L_m - Effective length of $L_C + L_R$ for mesh voltage, *m*;

L_R - Total length of ground rods, *m*

L_C - Total length of grid conductor, *m*

3. Equivalent Soil Resistivity in a Two-layer Soil Structure

In order to account for the influence of the soil structure, it is necessary to calculate the equivalent resistivity ρ_e.

The approximation of the horizontally stratified medium with homogeneous earth is accomplished using the following commonly used formula [2,4]:

$$\rho_e = \frac{D}{\frac{1}{\rho_n}\left(D - \sum_{i=1}^{n-1} h_i\right) + \sum_{i=1}^{n-1} \frac{h_1}{\rho_1}} \tag{3}$$

Where h_i is the thickness of the i-th layer and D is the penetration depth that depends on the grounding system dimensions and ρI is the resistivity of the i-th layer. According to [2, 4] the recommended values of D are between 30 m and 50 m. The Equation 3 for a two-layer soil is:

$$\rho_{e1,2} = \frac{D}{\frac{1}{\rho_2}\left(D - h_1\right) + \frac{h_1}{\rho_1}} \tag{4}$$

4. Calculation Procedure for Mesh Voltage

K_G has been determined for grounding grids with a square or rectangular shape. It is used as indicated in [1]: *S* for a square grid and *R* for a rectangular grid. The number after the letter indicates the number of cells in the grid. Because in practice a grounding grid has a large number of meshes, the following kinds of grids are tested from *S*16 to *S*256 and from *R*16 to *R*256. It is assumed for most of the cases that $\rho 1$=100 Ωm. *K*, which depends on the ratio between $\rho 1$ and $\rho 2$, has different values, shown in Table 1. The depth of the grid h = 0,5 and 1 m.

The following table represents the studied cases, which cover 720 situations of grounding grids without rods and different

<table>
<tr><td colspan="5">Grounding grids with a square shape without ground rods
S16, S64, S144, S256
h_1= 0,7m</td></tr>
<tr><td>Sizes, m</td><td>K</td><td>ρ_1/ρ_2</td><td>Case for comparison</td><td>h,m</td></tr>
<tr><td>50x50</td><td rowspan="3">±0,33
±0,82
+0,67
-0,9</td><td rowspan="3">1/10
1/5
1/2
2
10
20</td><td rowspan="3">$\rho_{ekv}= \rho_1$</td><td rowspan="3">0,5
1,0</td></tr>
<tr><td>100x100</td></tr>
<tr><td>200x200</td></tr>
<tr><td colspan="5">Grounding grids with a rectangular shape without ground rods
R16, R64, R144, R256
h_1= 0,7 m</td></tr>
<tr><td>Sizes, m</td><td>K</td><td>ρ_1/ρ_2</td><td>Case for comparison</td><td>h,m</td></tr>
<tr><td>50x100</td><td rowspan="3">±0,33
±0,82
+0,67
-0,9</td><td rowspan="3">1/10
1/5
1/2
2
10
20</td><td rowspan="3">$\rho_{ekv}= \rho_1$</td><td rowspan="3">0,5
1,0</td></tr>
<tr><td>100x200</td></tr>
<tr><td>200x400</td></tr>
</table>

Table 1. Studied Cases

ratios between ρ_1 and ρ_2. To allow comparison between the situations when E_m is calculated by using just one layer of soil (ρ_1) and the suggested simplified method using equivalent resistivity $\rho_{e1,2}$ (Eq. 3), there is "Case for comparison" in Table 1.

* For $K = -0{,}9$ $\rho_1 = 1000\ \Omega$m ; $K = -0{,}82$ $\rho_1 = 500\ \Omega$m and for other values of K $\rho_1 = 100\ \Omega$m

4.1. Results for K_G for Grounding Grids with a Square or Rectangular Shape at Different Sizes and K:
For all cases in Figure 1 to Figure 7:

1 - K_G is obtained with equivalent resistivity $\rho_{e1,2}$ (Eq. 4);

2 - K_G is obtained with equivalent resistivity $\rho_{ekv} = \rho_1$.

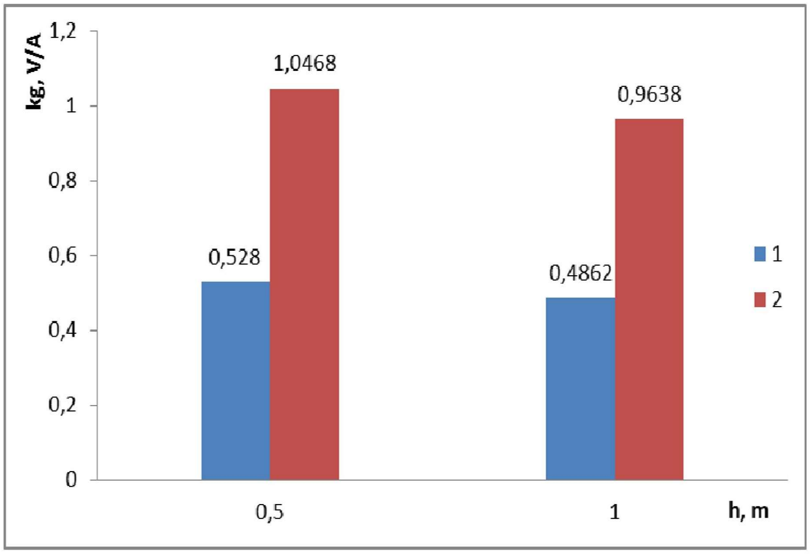

Figure 1. K_G versus h for S64 100x100; $K = +0{,}33$

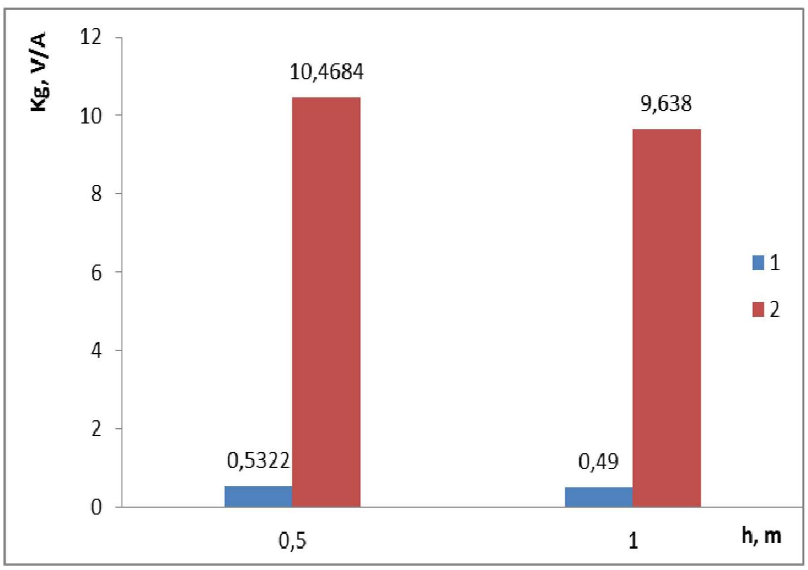

Figure 2. K_G versus h for S64 100x100, $K = -0{,}9$

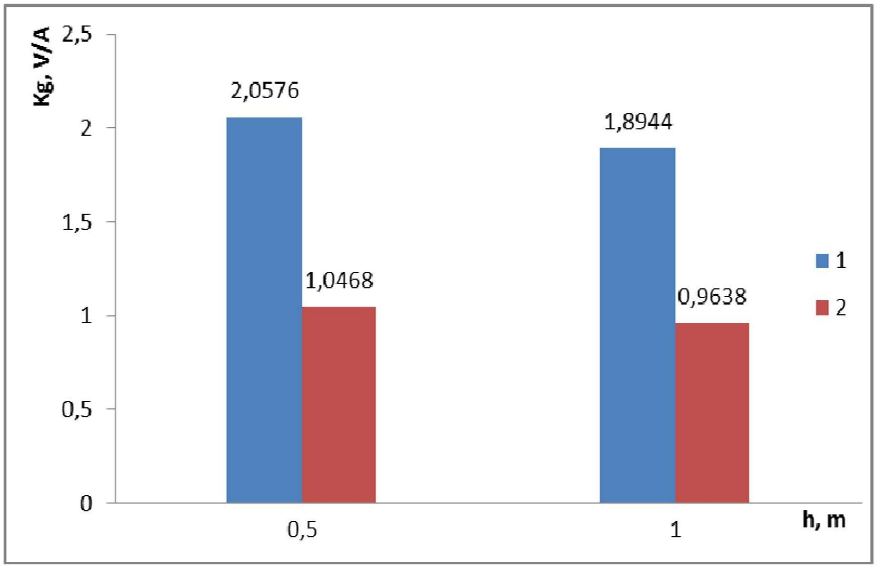

Figure 3. K_G versus h for S64 100 x 100, K= + 0, 33

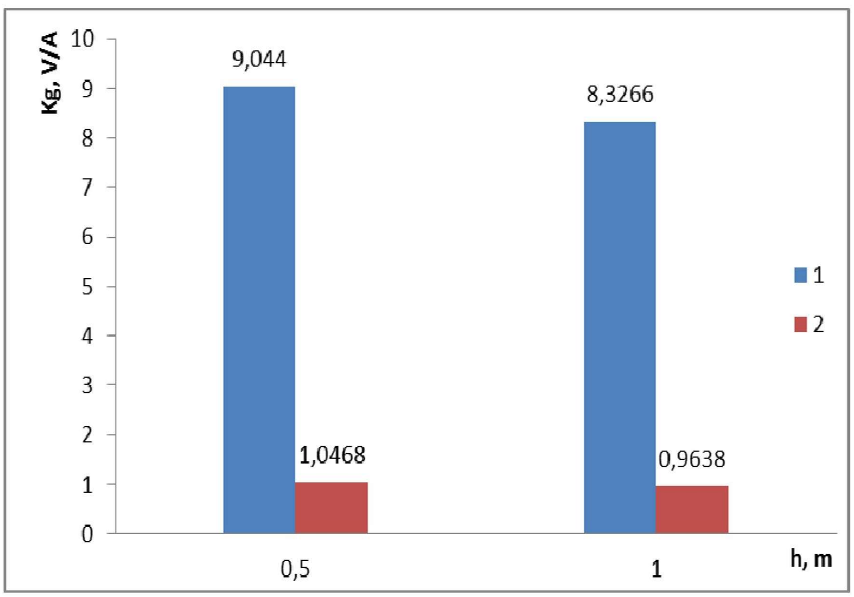

Figure 4. K_G versus h for S64 100x100, K= + 0, 82

4.2. Results for K_G when the Grid is in the First Layer (ρ_1) at Depth h = 0,5 m and $\rho_1 > \rho_2$.

Table 2 and Figure 8, Figure 9 present the results for K_G when the grid is in the first layer (ρ_1) at a depth h = 0,5 m. For S64 100 x 100 m and R64 100x200$\rho_1 > \rho_2$; ρ_1 / ρ_2 = 2; 10; 20 and negative K:

ρ_{ekv1} at K= - 0,33 (ρ_1= 100Ω.m; ρ_2 = 50 Ω.m);

ρ_{ekv2} at K= - 0,82 (ρ_1 = 500Ω.m; ρ_2 = 50 Ω.m);

ρ_{ekv3} at K= - 0,9 (ρ_1 = 1000Ω.m; ρ_2 = 50 Ω.m); ρ_1= 100 Ω.m

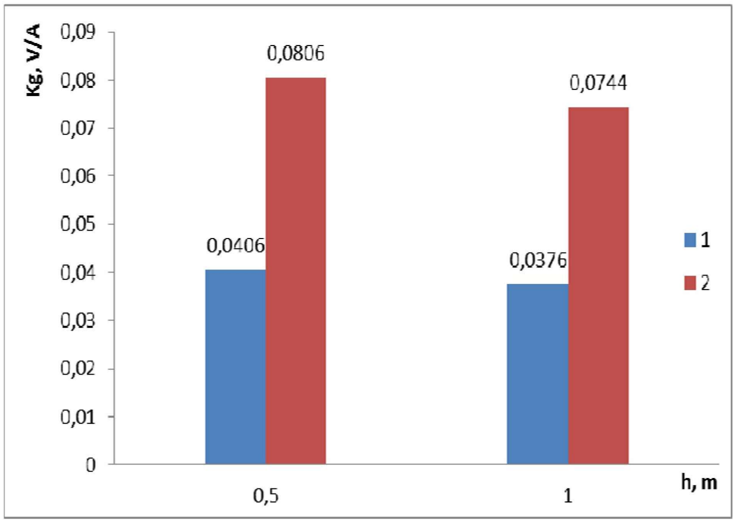

Figure 5. K_G versus h for R64 100 x 200; K = - 0, 33

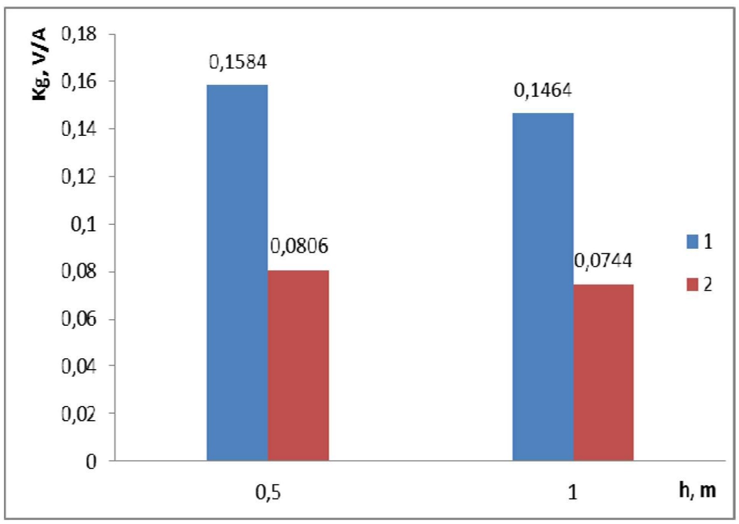

Figure 6. K_G versus h for R64 100x200; K= + 0, 33

4.3. Results for K_G when the Grid is in the First Layer (ρ_1) at Depth h = 0,5 m and $\rho_1 < \rho_2$.

Table 3, Figure 8 and Figure 9 present the results for K_G when the grid is in the first layer (ρ_1) at depth h = 0,5 m. For S64 100x100 m and R64 100x200 $\rho_1 < \rho_2$; ρ_1 / ρ_1 = 1/2; 1/5; 1/10 and positive K:

ρ_{ekv1} at K= + 0, 33 (ρ_1 = 100Ω.m; ρ_2 = 200 Ω.m);

ρ_{ekv}	K	ρ_1/ρ_2	S64	R64
ρ_{ekv1}	- 0,33	2	0,528	0,0406
ρ_{ekv2}	- 0,82	10	0,5318	0,041
ρ_{ekv3}	- 0,90	20	0,5322	0,041
$\rho_1 = \rho_2$=100 Ω.m	0	1	1,0468	0,0806

Table 2. K_G for Grid in the First Layer (ρ_1) $\rho_1 > \rho_2$

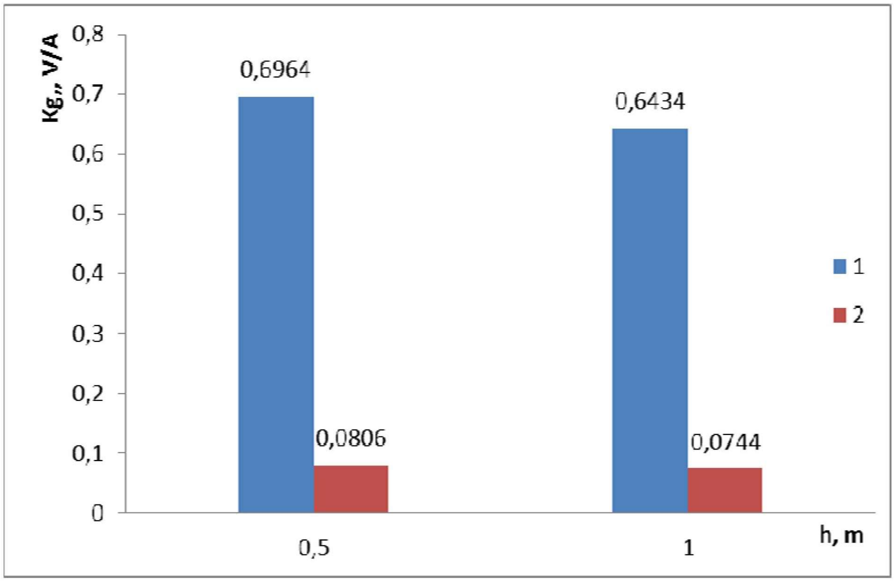

Figure 7. K_G versus h for R64 100x200; $K=+0,82$

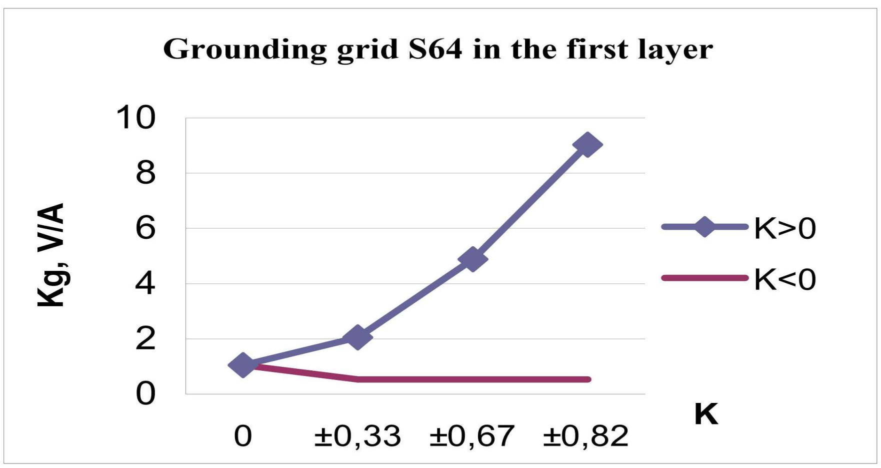

Figure 8. K_G versus K for S64 100x100

ρ_{ekv}	K	ρ_1/ρ_2	S64	R64
ρ_{ekv1}	+ 0,33	1/2	2,0576	0,1584
ρ_{ekv2}	+ 0,67	1/5	4,8918	0,3768
ρ_{ekv3}	+ 0,82	1/10	9,044	0,6964
$\rho_1=\rho_2=100\ \Omega.m$	0	1	1,0468	0,0806

Table 3. K_G For Grid in the First Layer (ρ_1) $\rho_1 < \rho_2$

4.4. Results for K_G when the Grid is in the Second Layer (ρ_2) at Depth h = 1, 0 m and $\rho_1 > \rho_2$

Table 4 and Figure 9, Figure10 present the results for K_G when the grid is in the second layer (ρ_2) at depth h = 1, 0 m. For S64 100x100 m and R64 100x200 $\rho_2 > \rho_2$; ρ_1 / ρ_2 = 2; 10; 20 and negative K (the values are the same as in B).

ρ_{ekv}	K	ρ_1/ρ_2	S64	R64
ρ_{ekv1}	- 0,33	2	0,4862	0,0376
ρ_{ekv2}	- 0,82	10	0,4896	0,0378
ρ_{ekv3}	- 0,90	20	0,4890	0,0378
$\rho_1 = \rho_2$=100 Ω.m	0	1	0,9638	0,0744

Table 4. K_G for Grid in the Second Layer (ρ_2) $\rho_1 > \rho_2$

4.5. Results for K_G when the Grid is in the Second Layer (ρ_2) at Depth *h* = 1,0 m and $\rho_1 < \rho_2$

Table 5 and Figure 10, Figure 11 presents the result for K_G when the grid is in the second layer (ρ_2) at a depth h = 1, 0 m. For S64 100x100 m and R64 100x200 $\rho_1 < \rho_2$; ρ_1 / ρ_2 = 1/2; 1/5; 1/10 and positive K (the values are the same as in C).

ρ_{ekv}	K	ρ_1/ρ_2	S64	R64
ρ_{ekv1}	+ 0,33	1/2	1,8944	0,1464
ρ_{ekv2}	+ 0,67	1/5	4,5038	0,348
ρ_{ekv3}	+ 0,82	1/10	8,3266	0,6434
$\rho_1 = \rho_2$=100 Ω.m	0	1	0,9638	0,0744

Table 5. K_G for Grid in the Second Layer (ρ_2) $\rho_1 > \rho_2$

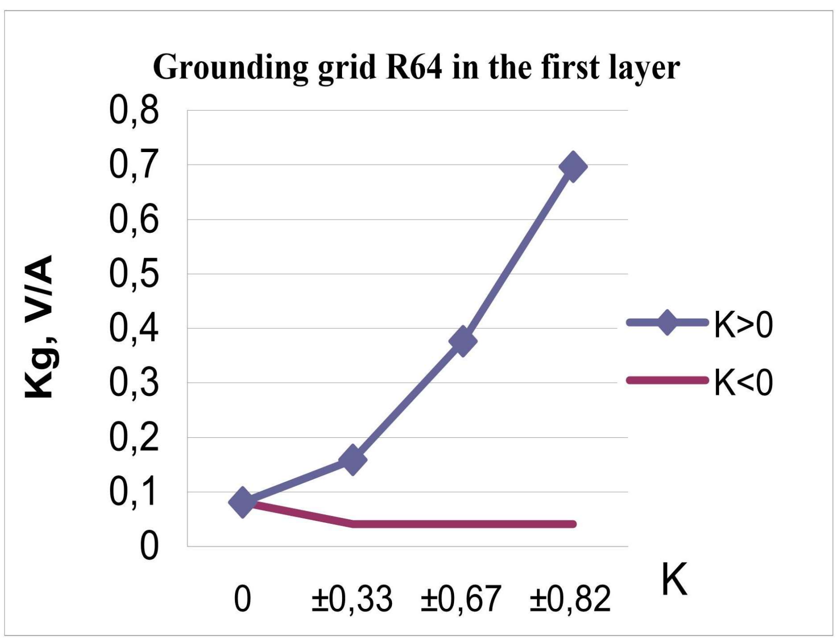

Figure 9. K_G versus K for R64 100x200

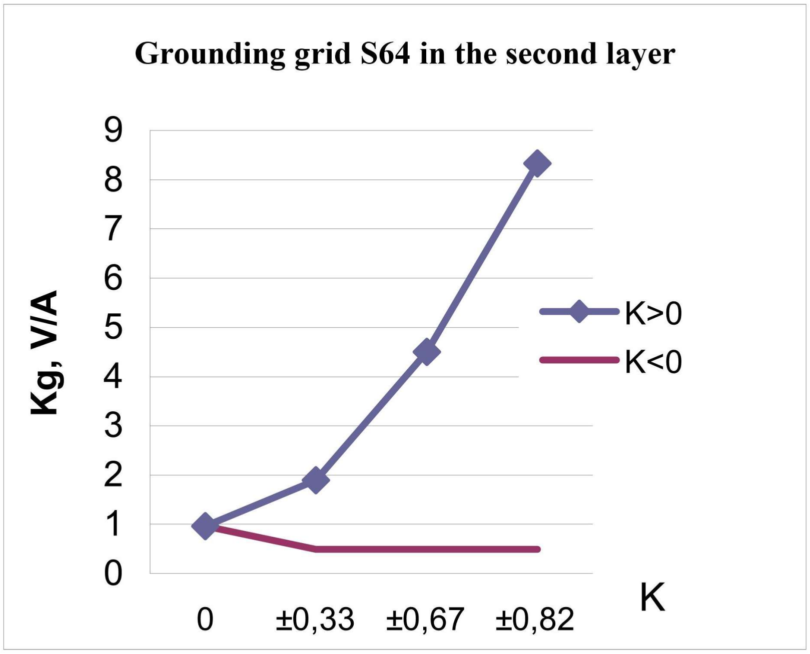

Figure 10. K_G versus K for S64 100x100

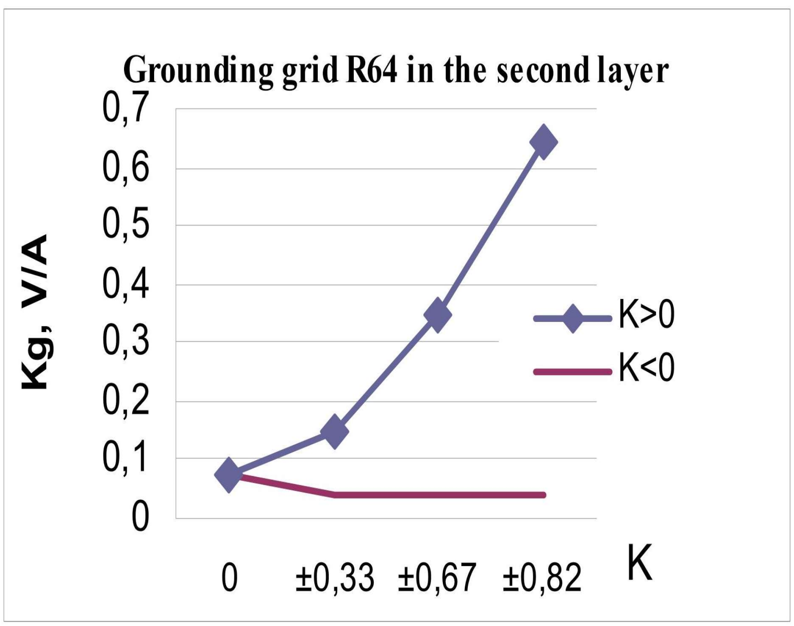

Figure 11. K_G versus K for R64 100x200

5. Conclusion

1. The method and the computer program of the paper are confirmed using the discussion in *F* [1] about the values of the resistance of the grid for negative and positive *K*.

2. The results obtained at negative *K* showed that the value of K_G for the cases using ρ_{ekv} can be up to 20 times lower than the case of calculation with ρ_1. It leads to resizing and higher costs.

3. For positive K the value of K_G can be up to 2 times larger than the case of calculation with ρ_1. It means that the values obtained for Em will be lower than the real ones, which affects electrical safety.

4. If the grid is either in the first layer or in the second layer at negative K, the range of change of K_G calculated without ρ_{ekv} (with ρ_1) is less than the one at positive K.

5. For a two- layer soil it is convenient to use the suggested simple way to calculate the equivalent resistivity and E_m.

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