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RESEARCH ARTICLE

Circumstances affecting the protection against electrode potential rise (EPR)

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Abstract

In this paper the grid resistance of substations with different earth electrode and soil structures is investigated by simulation studies with the use of CDEGS (Current Distribution, Electromagnetic Fields, Grounding and Soil Structure Analysis) software code. The paper presents the effect of grid geometry, soil characteristics, the effectiveness of the vertical earth rods and the conductor diameter.

Keywords

Earthing grid · substation · grid resistance · simulation

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1 Introduction

Required power of the big cities keeps growing year by year. It is necessary to establish new high voltage (HV) / medium voltage (MV) transformer stations to satisfy power demand in densely populated urban areas. The area available for installing HV/MV substation is restricted and becomes more and more expensive in the city. Considering this condition grid resistance of the substations must be low enough to satisfy safety (step voltage, touch voltage, earth potential rise) and electromagnetic compatibility requirements (earth potential rise, potential difference inside the station affecting the secondary wiring).

Simulation study has been done to assess the effect of the following circumstances affecting the grid resistance:

- Geometrical dimensions of substation earthing system
- Mesh size of the grid
- Application of the driven vertical rod electrodes (deep earth rods)
- Soil characteristics (value of the specific resistivity and stratified structure).

In case of simply grid arrangements the grid resistance can be determined with analytical expressions given in the technical literatures [1, 2].

Nowadays the grid resistance of complex earthing systems with the consideration of the actual soil resistivity values and structures of stratified earth can also be calculated by sophisticated computer codes base on numerical techniques [3].

In this paper the effects of the above listed condition on the grid resistance are investigated and the relative importance of the different parameters is evaluated.

2 Simulation technique

The resistance of an investigated earthing system has been calculated, by definition, as the ratio of the earth potential rise (EPR) and the current causing it (Ohm's law). That is why current injection technique has been used. Thus, a test current has been injected into the grid, which has caused a potential rise on the grid. The ratio of the potential rise to the remote earth at the current injection point and to the current value gives the grid resistance. Injected current in all cases is 10 kA with zero phase angles.

Injection point was placed on the centre of the grid except when the grid is a single frame where it is one of a corner points.

3 Examined variations

Grid resistance depends on above-mentioned circumstances. In this paper the following effects were studied:

- Total length of conductors (mesh size of theirs)
- Diameter of the conductors
- Soil structure, uniform and two layered
- Value of the soil resistivity
- Application of driven vertical rod electrodes
- Theirs combinations

The area of earthing system of substations installed in densely populated urban areas is generally about 400 m^2. Accordingly a quadratic, 400 m^2 earthing grid is used during the simulations (Fig. 1).

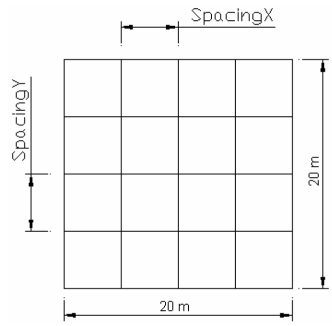

Fig. 1. Mesh size of the grid

Considering this size it is a special problem to keep grid resistance low enough value. The examined cases concerning the grid structure and mesh sizes are given in Table 1. In all cases the grid depth is 0.8 m. The basic value of the grid resistance in p.u. belongs to the 5 by 5 m mesh size.

Soil characteristic

From the point of view of grid resistance the soil resistivity, stratification, thickness of layers, number of layers is determinant.

Two cases were examined, on the one hand the soil is uniform and the other hand it was a two-layer soil (Fig. 2).

4 Presentation of the results

The grid resistance obtained from the simulations is usually plotted vs. the total length of conductors. Grid resistance as a function of total length of conductors is shown in the Fig. 3.

A good earthing system provides a low resistance to remote earth in order to minimize the EPR. For most transmission and other large substations, the ground resistance is usually about 1 Ω or less. In smaller distribution substations, the usually acceptable range is from 1 Ω to 5 Ω, depending on the local conditions [2].

In this case, the highest value also is less than 2.8 Ω, even if the "grid" is just a frame. Small mesh size of the conductors causes that the establishment cost becomes more expensive. Therefore in the practice, the average mesh size of conductors is about 3 m to 6 m. Considering this fact the grid resistance is about 2.22 Ω at 5 by 5 m mesh size. But it must be mentioned

Tab. 1. Examined cases of the mesh size of grid (ρ_{soil} =100) Ωm

Conductor		Grid		Grid resistance	
Total length [m]	Total surface [m^2]	Spacing X [m]	Spacing Y [m]	[Ω]	p.u.
80	5.03	20	20	2.76	1.24
100	6.28	20	10	2.56	1.15
120	7.54	10	10	2.44	1.10
140	8.80	20	5	2.35	1.06
160	10.05	10	5	2.30	1.03
200	12.57	5	5	2.22	1.00
220	13.82	20	2.5	2.21	0.99
240	15.08	10	2.5	2.18	0.98
280	17.59	5	2.5	2.15	0.97
360	22.62	2.5	2.5	2.11	0.95
460	28.90	20	1	2.13	0.96
480	30.16	10	1	2.09	0.94
520	32.67	5	1	2.06	0.93
600	37.70	2.5	1	2.04	0.92
840	52.78	1	1	2.02	0.91

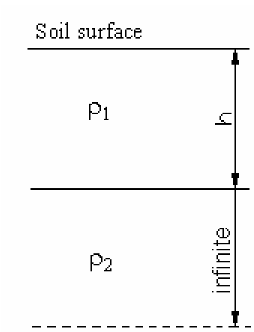

Fig. 2. Model of two-layer soil

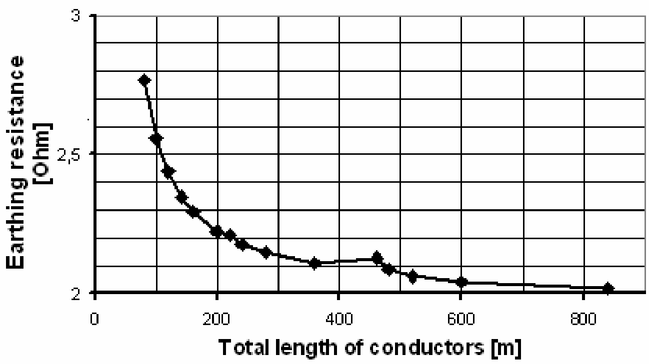

Fig. 3. Grid resistance vs. conductor length (ρ_{soil} =100 Ωm, uniform soil)

that the potential difference inside the grid could be require the mesh size decrementing to ensure EMC requirements of the secondary cables.

Regarding the effect of the change of *conductor diameter*, the total surface is growing with the increase of the diameter, which causes a decrease in the grid resistance. If the diameter is doubled the grid resistance changes less than 5 %. The *material* of the grid does not influence the grid resistance [4].

Grid resistance is directly proportional to soil resistivity in that case of uniform soil while this relation is non-linear when the soil is non-uniform (e.g. stratified). This non-linear function is presented in the Fig. 4, in case of two-layered soil structure. ρ_1 and ρ_2 are the resistivity of the upper and the lower layers, respectively (see Fig. 2). Thickness (h) of the upper layer is 5 m while the lower is infinite in depth. Parameter is the upper layer resistivity. It can be stated, that the earthing resistance

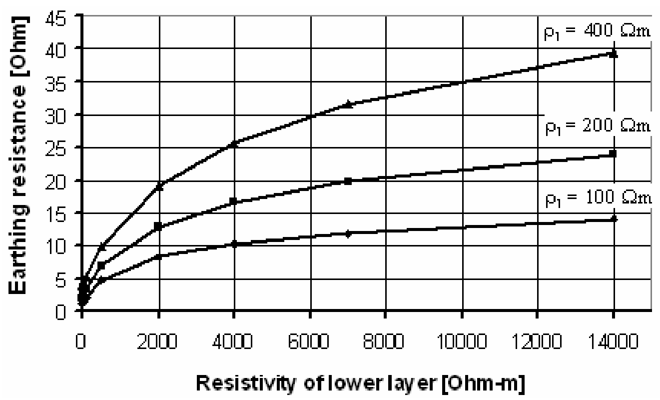

Fig. 4. Grid resistance vs. the resistivity of the bottom layer, Parameter is the resistivity of the upper layer (total length of conductors is 200 m)

significantly increases with the bottom layer resistivity but this changing is non-linear.

Another option is that case when the upper layer has a lower resistivity than the bottom layer. It is shown on the Fig. 5.

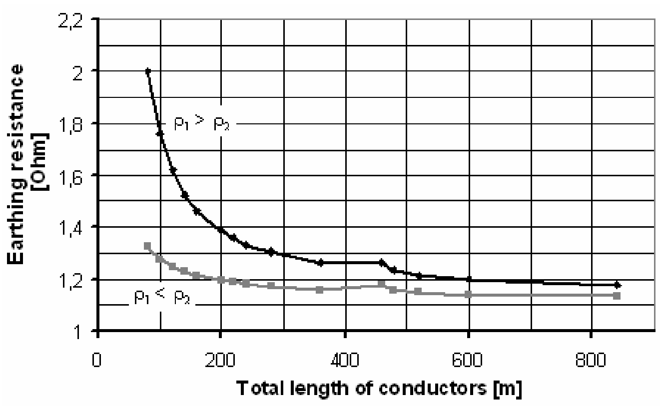

Fig. 5. Grid resistance vs. conductor length,
Parameter: ratio of the resistivities of the two layers, i.e. 30 and 100 Ωm

As it can be seen in the figure it is favourable if the top layer has lower resistivity.

Vertical earth rods

Accordingly to the standards concentrated earthing have to apply for the surge arresters and the star point of the transformer(s) in the transformer stations. The mentioned concentrated earthing can be vertical earth rod. The effect of such rods has also been investigated.

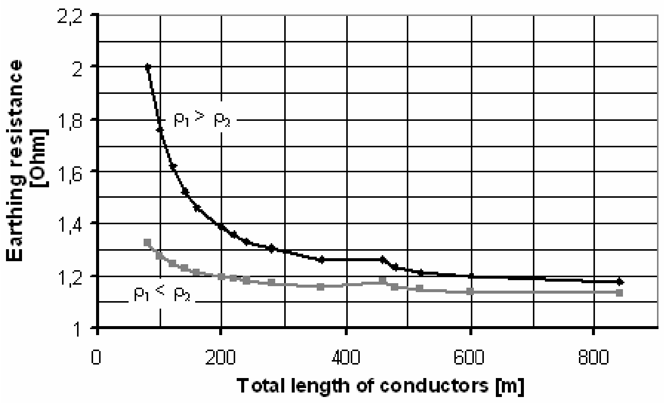

Fig. 6. Grid resistance vs. conductor length. Parameter: application of vertical rod electrodes (Uniform soil: ρ_{soil} =100 Ωm)

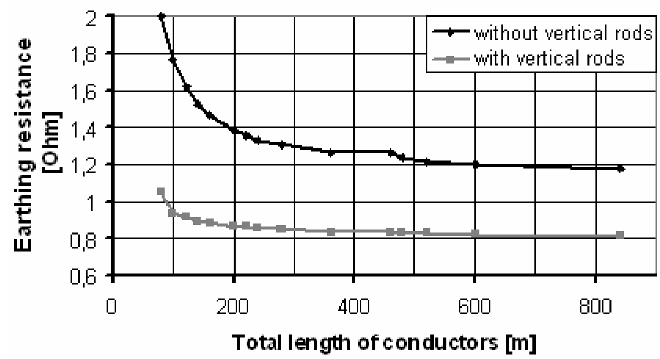

Fig. 7. Grid resistance vs. conductor length. Parameter: application of vertical rod electrodes (Two-layer soil: ρ_1 =100 Ωm, ρ_2 =30 Ωm)

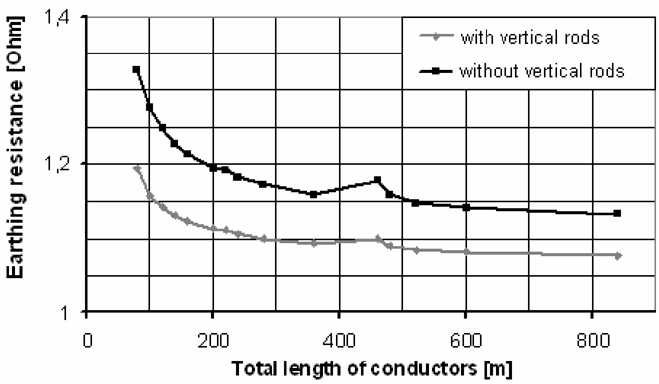

Fig. 8. Grid resistance vs. conductor length. Parameter: application of vertical rod electrodes (Two-layer soil: ρ_1 =30 Ωm, ρ_2 =100 Ωm)

The earth rods were placed at the centre and the four corners of earthing grid except when the grid was only a frame then, of course, no rod was applied at the centre. The length of each rod is 10 m.

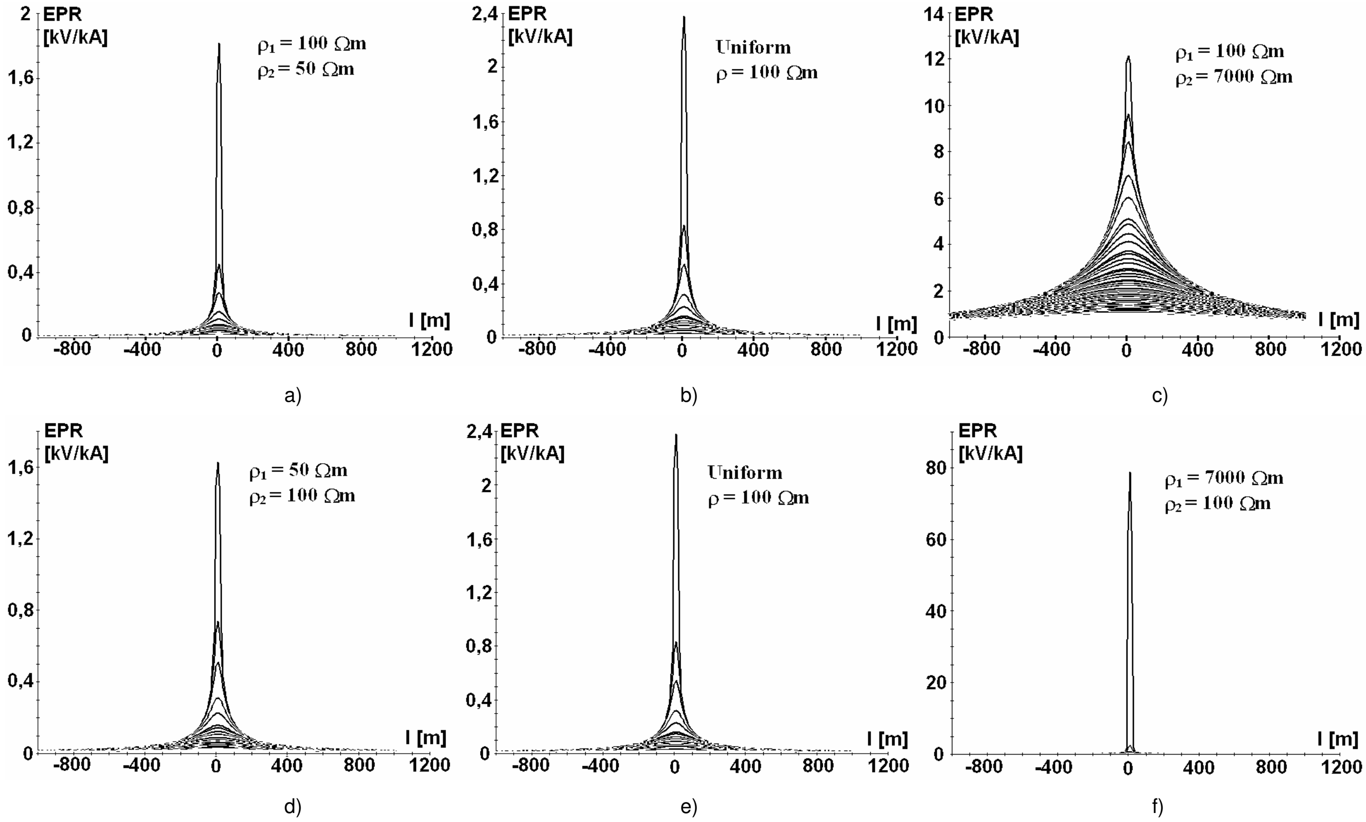

Fig. 9. EPR vs. distance from the earthing grid.

The uniform soil is a theoretical model because in the most practical cases the soil is usually stratified, non-homogeneous medium.

When the *soil* is uniform, the grid resistance decreases due to the application of the vertical earth rods. This effect is presented on the Fig. 6. The difference between cases (with and without vertical rods) is about 10 %.

The grid resistance curves in that case when the soil is two layered is shown in Fig. 7. The difference between the grid resistance of the grid with and without vertical earth rods is more than in the above-mentioned case. *Vertical earth rods* make a "direct" contact between layers, thus resulting in lower grid resistance.

That case when resistance of the top layer is lower than the bottom layer is presented in Fig. 8.

This soil structure results in significantly lower earth resistance even without the earthing rods. Or in other words, the improvement in the grid resistance due to the rod electrodes is much less than in that case when the bottom layer has the smaller resistivity.

Earth potential rise (EPR)

Different soil structures cause different earth potential rises. In addition the potential cone depends on soil structure. Two cases were investigated: on the one hand the soil is two layered and the bottom layer has constant resistivity, and the other hand the top layer has constant resistivity.

The reference value of EPR and the reference shape of potential cone belongs to the uniform soil with 100 Ωm resistivity in all cases (Fig. 9 b) and e)). The changing of potential cone and EPR can be seen in the first row when ρ_1 is constant and in the second row when ρ_2. The centre of the earthing grid (mesh size: 5 by 5 m, basic area: 400 m^2) is in the 0 point. From the results it can be drown that especially disadvantageous is that case when the upper layer has the smaller resistivity than the bottom layer.

The maximum EPR values are shown in Fig. 10. The reference value is 2,4 kV which belongs to the uniform soil (ρ = 100 Ωm).

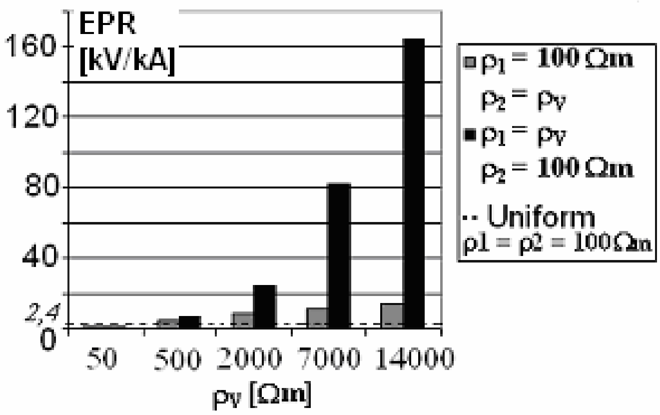

Fig. 10. EPR values in different cases.

Changing of wideness of the potential cone is plotted in Fig. 11. The reference value is 134,5 m which belongs to the uniform soil (ρ = 100 Ωm).

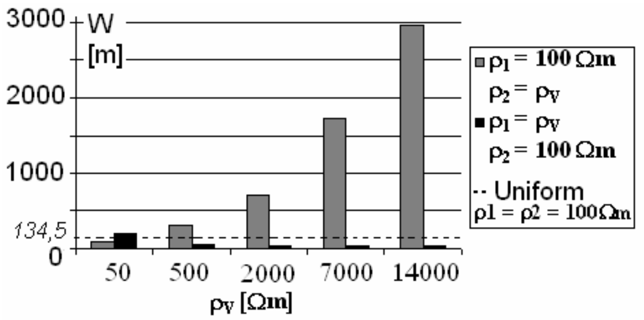

Fig. 11. Diameter of potential cone at 10% of maximum EPR values.

5 Conclusion

The grid resistance can be determined with analytical expressions given in the technical literatures in case of simply grid arrangements for homogenous soil structure [1, 2].

In this paper sophisticated computer code based on numerical techniques [3] are applied for the investigation of the grid resistance of earthing systems with the consideration of the different soil resistivity values and stratified earth.

Simulation study has been done to assess the effect of the following circumstances affecting the grid resistance: geometrical dimensions of substation earthing system, mesh size of the grid, application of the driven vertical rod electrodes, soil characteristics (value of the specific resistivity and stratified structure).

From the numerical results obtained, the following main conclusions can be drown:

- The decrease of the mesh size of the grid results in significant decrease in the grid resistance up to size 5 by 5 m.
- In case of stratified soil structure the grid resistance does not change anymore proportionally to the resistivity of the soil.
- The application of vertical rods improves the grid resistance significantly only in that case when the resistivity of the lower layer is the smaller one.
- The diameter of the conductor constituting the grid has of minor effect on the magnitude of the grid resistance.
- EPR and diameter of the potential cone depends on soil structure.
- In that case when the resistivity of the bottom layer is constant and the resistivity of the top layer is increasing, the maximum value of EPR changes approximately proportionally to the resistivity of the upper layer.
- In the opposite case diameter of the potential cone grows with increasing of the bottom layer resistivity.

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