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Application of modern methods computing geoelectrical models to complex ground structure analysis

***Abstract**. The aim of this paper is to propose the appropriate geoelectrical model of ground structure based on soil resistivity measurements made in Huta Poreby Research & Development (R&D) Area of Rzeszow University of Technology (RUT). Analysis and comparison of typical ground structure models including multilayer conception have been done in several different configurations of grounding system. To obtain appropriate result two interfaces of CDEGS have been used: RESAP and MALT.*

***Streszczenie.** Celem pracy jest zaproponowanie modelu struktury geoelektrycznej gruntu w oparciu o badania rezystywności gleby wykonane na terenie Poligonu Badawczego Politechniki Rzeszowskiej. Analiza i porównanie typowych modeli geoelektrycznych ze szczególnym uwzględnieniem koncepcji wielowarstwowej zostały przeprowadzone dla kilku konfiguracji układu uziemienia z wykorzystaniem dwóch modułów pakietu CDEGS. (**Wykorzystanie nowoczesnych metod obliczania modeli geoelektrycznych do złożonych analiz struktury gruntu**).*

Keywords: soil structure and resistivity, LPS, grounding resistance
Słowa kluczowe: struktura geoelektryczna oraz rezystywność gruntu, instalacja odgromowa, rezystancja uziemienia

Introduction

Presently geoelectrical modelling is important branch of electrical engineering. Soil resistivity models are basis of computing total resistance of grounding systems. Mostly uniform or two layer models are sufficient to determination of resistivity distribution in the ground. Unfortunately there are some cases when models should be more accurate. For example in case of complex grounding systems buried in high-resistive soils or where total system resistance is required to be low. Therefore multilayer model with horizontally placed layers of different resistivity has been analysed.

Research has been done in Huta Poreby R&D Area of RUT located in south-east part of Poland. Terrain is situated in non-urbanized area. Any metallic structures such as grounding grids of stations, pylons, pipelines do not exist. An arrangement of the main facilities is shown in Fig.1.

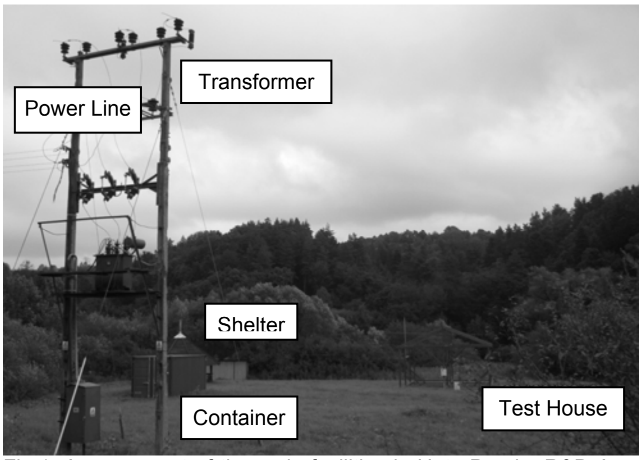


Fig.1. Arrangement of the main facilities in Huta Poreby R&D Area of RUT.

Among the objects it is worth to distinguish 500 meter open circuit low voltage line, T3ZONe 30/20 15kV/400V supply transformer and YAKY 4x35 mm^2 buried cable. In the middle of the area test house is located. The house is equipped with LPS composed of two vertical 61 cm length rods (U1, U2). The rods are buried in the opposite corners of the building and connected together by LPS system static wire (Fig.2). Above the cable 4x25 mm metal tape (B) 16 m length is arranged. The aims of this procedure are to protect the cable from transferred potentials and additionally to reduce LPS grounding system impedance. Connection between the tape and LPS system indicated Z in Fig 2. has been examined on different configurations.

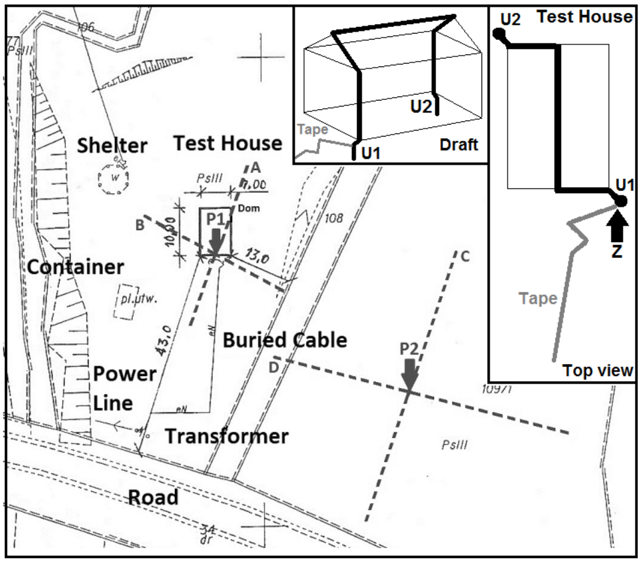


Fig.2. Locations of soil resistivity measurement profiles with additional drafts of test house and tape grounding.
Profiles A & B – July 9, 2009; profiles C & D – September 22, 2010.
Notice: bold lines indicate wired connections between grounding rods (U1, U2) of LPS system.
Map scale 1:1000; source material: WGiK.

Two kinds of measurements have been made. Wenner method has been applied to obtain soil resistivity characteristics in different directions. Spacing between current and potential probes was the same ranged from 0.3 m up to 20 m. Probe-depth varied from 10 cm for small probe spacing to 50 cm for large measuring distances [1]. During resistivity measurement only transformer grounding system was installed but due to distant no influence on the results can be assumed. The grounding system apparent resistance measurements aim was to verify computed geoelectrical soil resistivity model. Grounding parameters such as inductance and capacity have been neglected due to low frequency domain measurement done by MRU-101 multimeter.

More detailed information on the configuration and performance features of the measurement and facilities in the Huta Poreby R&D Area of RUT can be found in [2].

Analysis and comparison of typical ground structure models with the multilayer conception and discussion

Initial analysis have been made in CDEGS - a powerful set of integrated engineering software tools designed to accurately analyze problems involving grounding, electromagnetic fields and cathodic protection [3]. Based on sets of resistivity measurement data several ground structures have been analyzed in RESAP. Besides horizontal models such as the simplest uniform, two- and three-layer also exponential approach have been considered. Moreover author decided to examine two-layer model with assumed resistivity 150 Ωm of the top stratum. Obtained RMS error, which specifies the maximum acceptable root mean square between the measured data and the corresponding values generated from the computed soil model, confirmed thesis that uniform approach is correct only for soils with relatively low variations of resistivity. The locked model could be accurate on condition that analysed type of the soil is well known. In many cases this information is difficult to obtain without participation of experienced geophysicist or geologist. Remaining models show an approximate and satisfactory precision. Finally, to further analysis two-layer model was used as compromise between accuracy and simplicity. The examination of influence of depth and distance of measuring probes is presented in [2].

In order to verify correctness of the assumed model author has used another CDEGS module MALT where grounding system resistance has been computed. Five different configurations have been analysed. Two concepts of grounding system resistance are applied in CDEGS: apparent resistance and Ground Potential Rise (GPR). The GPR is a potential of the main electrode in respect of remote ground. Ratio of the GPR and a fault current is adopted as a substitutive resistance. On the other hand the apparent resistance which is total resistance obtained when any other metallic structures beyond the main grounding exist [3]. The next step was to compare the results with those measured from fall-of-potential method. Obtained precision about 10 % confirmed cases appearing in literature [4]. Many papers and books where lightning phenomena is studied suggest to use precise soil models in order to reducing error margin. Therefore to investigate the reasons of inaccuracies Fig.3 can be analysed.

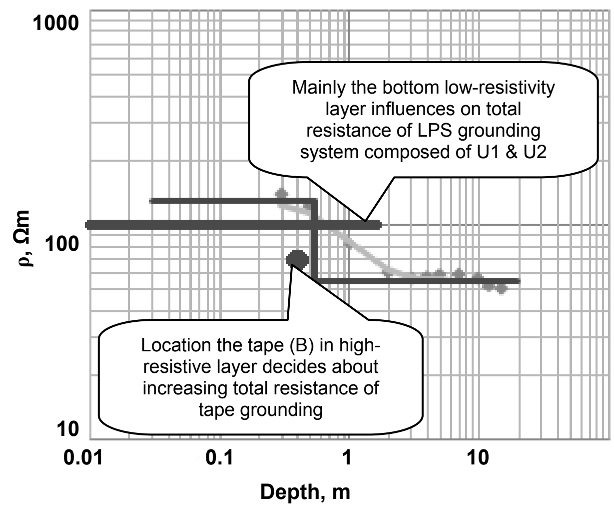


Fig.3. Graphical explanation of inaccuracies resulted from low-layer models. The depth of buried electrodes in compare with measured (scatter plot), approximated (smooth curve) and computed (step curve) resistivity curve has been presented in above panel.

It is interesting that, in comparison with real case, the apparent resistance obtained from the simulation is lower for rods and greater for the tape. Influence of deeper soil volumes with lower resistivity factor is significant. Author conclude even relatively small ground pieces could be predominant if its resistivity is properly low. The metal tape is buried at a depth of 0.45 m so it is located in the top stratum but close the boundary of the layers. The simulation has proved that mainly the upper layer determines resistance of the tape. Thus another suggestion could be made the system resistance is strictly dependent on resistivity characteristics of the soil volume near surface of the electrode. As consequence of the measuring circuit sensitivity it is difficult to obtain precision better than mentioned. The model should be better fitted in zone of the significant current density. Moreover thank to this assumption step and touch voltages will be determined more accurate.

The problems specified above can be solved by appliance of the multilayer ground structure model. The exponential model has been also analysed but unless low RMS error exponential curve has not been precise enough. Moreover in MALT is no opportunity to apply this kind of model yet. The most complex model enabled in the packet is 20-layer horizontal conception. It can be imported from RESAP directly and use as a background to grounding system resistance computations. An initial simulation with default settings have not been accurate. With the aim of improving performance different configurations of algorithms have been used (Marquart, Steepest-Descent) [5]. Nevertheless there was no significant improvement of results.

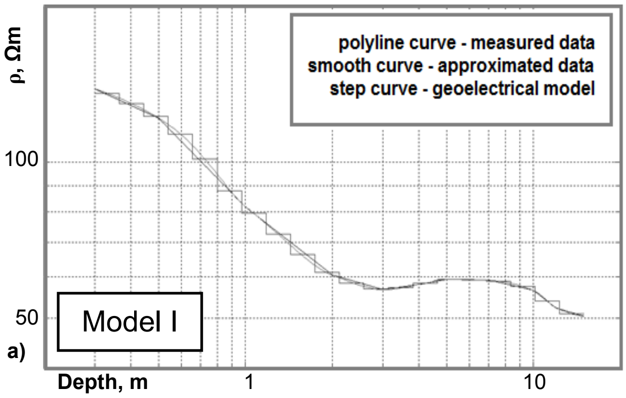
Necessity of further improvement forced to invent own algorithm. The program has been written in MATLAB language. The main procedure enables a useful set of functions which can optimize fitted multilayer ground model. Generally program input data are measured resistivity vector and corresponding probe spacing vector. It approximates scatter data as smooth curve which then is applied to compute target model curve. Algorithm acts on the assumption that derivative of approximated curve might be a certain function of layer thickness. Three cases of approximated curve fitting are possible: interpolation, approximation or extrapolation. User can also fit by polynomial function waveform. In the program soil is split into parts called zones. Zone is a horizontal ground volume which consists of one or more layers. Maximum number of layers is not limited. It is necessary to define thickness and depth of each zone in form of specific vector. Thanks to this approach layers density can be customized. Thickness of layers can vary or be identical within zone. Output data can be shown by MATLAB in figure window or Array Editor. Two column matrix consists of resistivity (left side) and thickness (right side) of specified layers. Notice that due to lossy air number of rows is one greater than the number of layers. The results can be easily exported to MALT and used to compute resistance of the considered grounding system. Only one condition must be satisfied all parameters must be locked if not MALT will change model automatically.

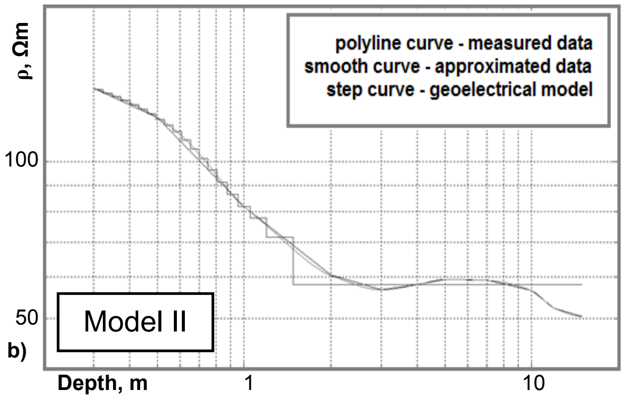
In case of verification the multilayer ground structure in Huta Poreby R&D Area of RUT several simulations has been made. A set of four 20-layer horizontal models has been prepared. In Tab.1 all conceptions are summarized. Two first models are free-defined for the simulation process. This type of structures is appropriate for preliminary computations. The second zone has been defined in relatively narrow range within quite a lot layers so the most sensitive soil volume near the tape surface is well-fitted. The following cases III and IV have been assumed on the basis of self experience and grounding system spatial configuration.

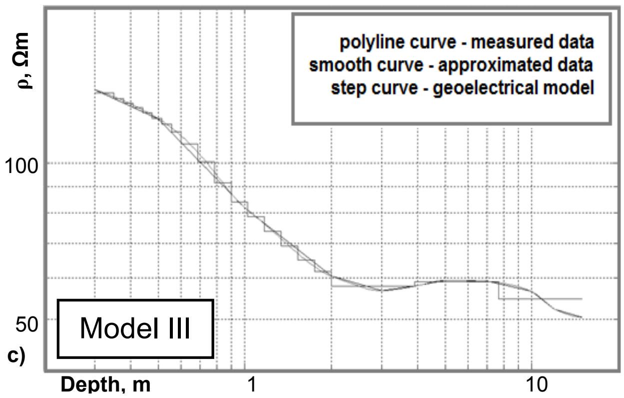
Table 1. Assumed conceptions of 20-layer horizontal ground structure models in the Huta Poreby R&D Area of RUT.

Model	Number of Zones	Characteristics	Layers Thickness
I	1	20 layers 0-15m	Uniform
II	1		Varied
III	4	1 layer 0-0.35m 7 layers 0.35-0.6m	Uniform
IV	4	9 layers 0.6-2m 3 layers 2-15m	Varied

Cause of fault current penetration depth which is estimated about two to five meters for clay soil [4] lower parts of the ground are simplified to three layers. The total model thickness of 15 m corresponds with measured data and strictly depends on maximum electrode-spacing distance of Wenner method. Current program version has no varied probe-depth option but this influence occurs only near the soil surface. Due to depth of considered grounding system can be negligible. The most interesting curves are presented in Fig.4.







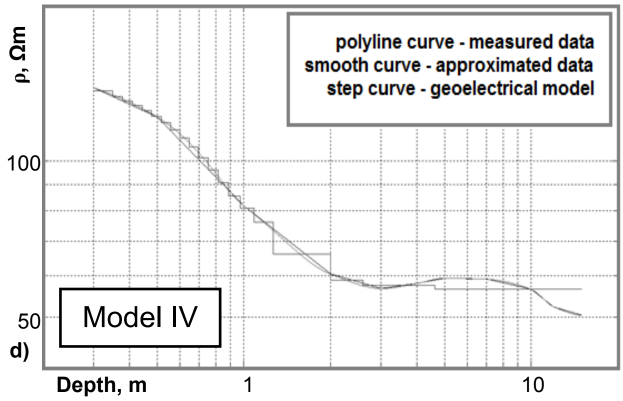


Fig.4. Computed ground structure models corresponding with P1A profile data set. Measured data (polyline); approximate (smooth curve); model (step curve). Notice: meaning of the curves is explained in the text.

In Figs 4a and 4c, where uniform thickness of the layers is shown, adapted model fits very well. In other cases, as a result of insufficient amount of layers, some divergence can be observed. Probably the most appropriate is model III. There can be easily seen a number of layers in the second zone where the tape is buried. The next advantage is the deeper soil volumes resistivity character is well remained.

The following step was to import computed models into the MALT. Due to complexity of the structure and profiles particular simulation the process lasted several minutes. Results based on MATLAB models are more accurate than from RESAP. In case of vertical rods U1 and U2 obtained precision was about 1 %. In more complicated configurations where the tape is involved accuracy was also at satisfying level of 6 %.

Conclusions

The multilayer conception serves many technical capabilities such as very high precision and compatibility with individual configuration of grounding system. Unfortunately simulation time is increased. Therefore use of this time-consuming method makes a sense only for research studies, wind farms or LPS-s where very low level of grounding system resistance must be provided. Analysis has proved thesis that new methods of optimization ground structure models enables to receive considerably accurate electrical parameters of grounding systems. Among two- three- and exponential layer structures only the multilayer conception provided precision of about 1 % which is new level of better performance of computing programs.

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