Influence of the Metal Installations in the Ground on the Measurement Results Accuracy of the Soil Resistivity

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Abstract-- Very often, the measurement of the specific electric resistivity of the soil performed by one of the commonly used methods introduces errors in results because of the existence of certain metal installations buried in the ground, like aqueducts, water or drainage pipes, metal strips or metal sheaths of power cables etc. An attempt has been done in the paper to give some recommendations while displacing the measuring system in order to avoid the impact of such metal installations on the measured results, and thus to avoid the eventual errors that can occur during the measurement.

Index Terms influence, measurement, metalinstallations, and soil resistivity.

1. INTRODUCTION

The specific electric resistivity of the soil ρ is a parameter, that all the more important characteristics of the grounding change proportionally with: resistance to ground, potentials, distribution of currents flowing into the earth from the separated elements of the grounding (electrodes), distribution of the potentials on the surface of the earth, step and touch voltages etc. It's very important to measure this parameter as precisely as possible, so that the design of the grounding would be correct and economical. There are many methods for geoelectric examination of the soil, and one of the most used is the Wener's, reference [2]. It's characteristic is the use of four electrodes (probes) buried in the earth making the measuring system. Two of them, the outer electrodes are with current, and two of them, the internal ones, called voltage probes, are with voltage. They are symmetrically arranged in the same direction, and the distance a between any two neighbouring electrodes is equal (fig. 1). Between the ending points of the first and the fourth electrode, a voltage source is plugged in, that zhelps to establish a current circuit through the earth.At the ending points of the second and the third electrode, a voltmeter is plugged in, measuring the potential difference U established between these electrodes by the current.

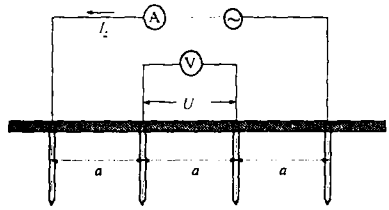

Figure 1. Disposition of the equipment of the measuring system according the Wener's method

No matter which method will be used for measuring, in the practice there are often cases of big deviations of the value of the measured specific soil resistivity during some small displacements of the measuring system. These differences can be a result of the distortion of the potential lines because of the presence of layers with different, much bigger or smaller specific soil resistivity ρ, and also because of the presence of different metal installations (aqueduct, water or drainage pipes etc). It's clearly shown that without a correct estimation of the presence of such metal installations, the error in the measuring the soil resistivity ρ can be quite unacceptable.

2. TAKING INTO CONSIDERATION THE PRESENCE OF THE METAL INSTALLATIONS - A MODEL

The metal installations (aqueduct water or drainage pipes etc.) can be closely examined as passive grounding electrode or a grounding electrode on zero potential with an infinite length in relation to the measuring system. This kind of representation is fully justified, if we consider that these kinds of installations are most frequently connected through the neutral conductor of the low voltage network. Because of that, it can be assumed that the measuring system is placed in the very medium of the metal installation. If the two current probes are treated as two electrodes so that from one of them a particular current is leading out $+I_Z$ and I_Z is flowing into the other one, in that case, we get a system of five mutually coupled grounding electrodes. Two of them are active, the current electrodes, two of them are passive, the voltage electrodes, and the fifth one is passive (i.e. of zero potential)-the metal installation. If the metal installation is in the potential funnels of the active grounding electrodes, distorting the potential lines, its influence has to be taken into account. In that case the metal installation, as a grounding electrode, should be divided into several short parts (electrodes), as short as possible, i.e. with length twice or three times smaller than the distance a between any two neighbouring electrodes of the measuring system.

The impact of the mutual influence between the grounding electrodes, galvanically separated, leeds to the calculation of several mutually coupled grounding systems. For solution of this problem, different procedures can be used. In the past, it used to be done in an experimental way, using the electrolytic bath, but since the computers appeared, the numerical methods and procedures have been used more and more for that purpose. Numerical methods enable determination of the potentials in different points in the environment of the grounding elements. They are usually based on the existing formal analogy of the mathematical relations of the electrostatic field and the stationary current field.

The Maxwell's equations are written one for each element of the grounding systems. In fact, they are relations between the potential of each element and the currents flowing into the earth from all electrodes of the grounding systems. That way, a system of linear equations is obtained. The solution of this system is the currents flowing into the earth from the elements of the grounding systems and their potentials. Afterwards, the potentials of the required points from the region are calculated too.

One of the most important problems here, taking the biggest part of the calculation time is determination of the coefficients of the system of Maxwell's equations i.e. calculation the self and mutual resistance's of the elements of the grounding system. When each of the grounding systems can be represented as a composition of linear, mutually coupled elements (tapes, pipes, ropes, bars etc.), the application of the method of medium potentials seems to be the most appropriate for calculation of the mentioned self and mutual resistance's in a numerical way, by means of computer. All calculations done in the paper have been carried out with a computer program package based on the method of medium potentials application, made by the authors.

We are observing now a general case of m galvanically separated grounding systems, like in [1] mutually resistantly coupled. If the k-th grounding system has n_k elements $k=1,2...m$, is valid:

$$\begin{bmatrix} [r] & -[B] \\ [B]^T & [O] \end{bmatrix} \cdot \begin{bmatrix} [I] \\ [U] \end{bmatrix} = \begin{bmatrix} [0_m] \\ [I_z] \end{bmatrix} \tag{1}$$

Where:

$$[B] = \begin{bmatrix} [1_1] & [0_1] & \cdots & \cdots & [0_1] \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ [0_k] & \cdots & [1_k] & \cdots & [0_k] \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ [0_m] & \cdots & \cdots & [0_m] & [1_m] \end{bmatrix}$$

$[r]$- Is a matrix of self and mutual resistance's of all electrodes from all grounding systems, with dimensions $\left[\sum_{k=1}^{m} n_k \times \sum_{k=1}^{m} n_k\right]$. While calculating the self and mutual resistance's, the images of the grounding elements, in relation to the plain of discontinuity (the surface of the earth) should be taken into account. When a two-layer or a multi-layer environment is in question, as it is usual case, the number of images is infinite.

$[I]$-A vector of the currents dissipating from all the electrodes of all grounding systems, with dimensions $\left(\sum_{k=1}^{m} n_k \times 1\right)$;

$[U]$-A vector of the voltages of the grounding systems, with dimensions $(m \times 1)$;

$[0_m]$- Zero vector with dimensions $(n_m \times 1)$;

$[I_z]$ -A vector of total earth currents flowing into the earth from the grounding systems, with dimensions $(m \times 1)$

$[O]$-Square zero matrix with dimensions $(m \times m)$ or zero vector $\left(\sum_{k=1}^{m} n_k \times 1\right)$

$[1_k]$ -A unit vector with dimensions $(n_k \times 1)$

$[0_k]$ Zero vector with dimensions $(n_k \times 1)$

The solution of (1) will be:

$$\begin{bmatrix} [I] \\ [U] \end{bmatrix} = [C] \cdot \begin{bmatrix} [0_m] \\ [I_z] \end{bmatrix} \tag{2}$$

Or:

$$\begin{aligned} [I] &= [F] \cdot [I_z] \\ [U] &= [R] \cdot [I_z] \end{aligned} \tag{3}$$

Where:

$$[C]=\begin{bmatrix} [r] & -[B] \\ [B]^T & [O] \end{bmatrix}^{-1}=\begin{bmatrix} [E] & [F] \\ [G] & [R] \end{bmatrix} \tag{4}$$

The square matrix $[R]$ with dimensions $(m \times m)$ is a matrix of the grounding resistance's of all m grounding systems where the diagonal elements are the self grounding resistance's (but in presence of the rest of m-1 grounding systems), and the non diagonal elements are the mutual resistance's, i.e. the partial contributions of the remained grounding systems, if they are active. The information about how the current will be distributed in the electrodes of all grounding systems is contained in the submatrix $[F]$.

The potential in the point M on the surface of the earth is:

$$\varphi_M = [r_{aM}]\cdot[I_a]+[r_{bM}]\cdot[I_b]+\cdots+[r_{mM}]\cdot[I_m] \tag{5}$$

Where $[r_{aM}][r_{bM}]....,[r_{mM}]$ are matrices of mutual resistance's of the electrodes a, $b,....,m$ and the point M.

By means of the method of medium potentials used for several number of mutually coupled grounding systems, we can calculate the potentials φ_2 and φ_3 of the voltage electrodes (probes) i.e. their difference U:

$$U=\varphi_2-\varphi_3 \tag{6}$$

For the problem from fig. 5 we get a system of 5 grounding electrodes, and by solving it, we can obtain the exact value of the specific resistance of the soil:

$$\rho_T = 2\cdot\pi\cdot a\cdot\frac{U}{I_Z} \tag{7}$$

If we disregard the existence of a metal installation, the grounding system will consists of 4 grounding electrodes, and through the relations (7), we get the value that would be shown by the measuring system ρ_M in the same way. The error in the measurement, in percents will be:

$$g=\frac{\rho_M-\rho_T}{\rho_T}\cdot 100 \tag{8}$$

3. ANALYSIS AND EXAMPLE

The analyses show that the error g in measurements depends a bit on the depth of buring the electrodes and the depth of the metal installation, as well as on the diameter of the probes and the metal installation. The only parameters that this error depends on a lot, is the relation d/a and the angle α, where d is the normal distance from the midpoint of the measuring system and the axis of the metal installation, and α is the angle between the axis of the metal installation and the axis of the measuring system.

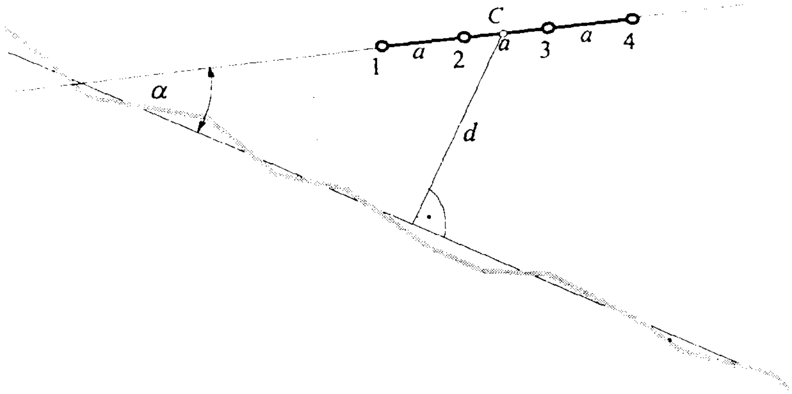

Figure 2. Disposition of measuring system and the installation

The further is the metal installation from the measuring system, the smaller is the error. The error is different for different angles, and it's the biggest for $\alpha = 90^\circ$. To avoid or diminish the error, we can approach to the problem in a way that we define in advance the limit of the allowed error in the measured result. This way, we can define an area around the midpoint of the measuring system, where a measurement should not be carried out, because in a case, there is an installation, the measuring error of the specific soil resistivity will be bigger than the preliminary specified one. For example, let us consider system in which the four electrodes are with diameter D = 24.5 mm, and are buried on the depth H = 0.5 m, and the metal installation in the ground is with diameter D = 110 mm, on depth H = 0.8 m. On figure 3, results for g =1%, 5%, 20%, 50% are presented. This error will not be overcome if the measuring system moves on a distance d bigger that the given one on the picture.

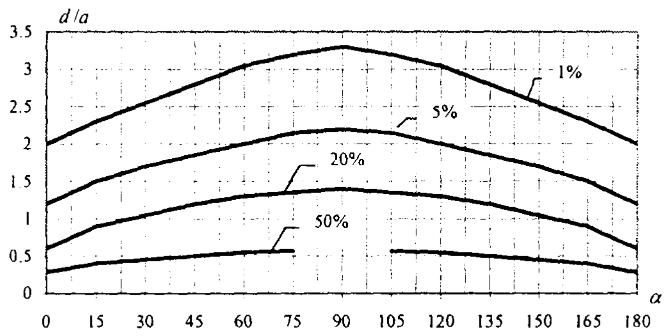

Fig. 3. Dependence of the ratio $d/a = f(\alpha)$ for different allowed levels of errors g %

If the midpoint of the measuring system is in the beginning of the rectangular co-ordinate system XOY, then for an angle $\alpha = 0^{\circ}$, we get the abscissa, and for angle $\alpha = 90^{\circ}$, we get the ordinate. If we draw the areas that have to be avoided during the measurements, so that the error in measurements introduced by the presence of the metal installation is less than the specified one, we get closed bents which could be approximated by ellipses, with smaller axis rx and bigger axis ry whose values depend on the specified percentile error g%. The values of these axes are given in table 1

Table 1. Values of the axis of the elypses in dependance of the allowed error in the measuring

$g\%$	rx	ry
1%	$2 \cdot a$	$3{,}3 \cdot a$
5%	$1{,}2 \cdot a$	$2{,}2 \cdot a$
20%	$0{,}6 \cdot a$	$1{,}4 \cdot a$
50%	$0{,}28 \cdot a$	/

However, in the practice, the soil is most frequently not homogenous. The experience says that the inhomogeneous soil can be modelled quite satisfactory by a two-layer model with different specific electric resistance's of the upper and the lower layer ρ_1 and ρ_2 - respectively, and depth of the upper layer h_1. In this case, the same procedure as with the homogeneous soil is valid. The difference is that the self and mutual resistances of the elements of the grounding systems in the model are calculated so that the infinite number of their images should be taken into account.

4. CONCLUSION

If, by a small shift of the measuring system, we get results for specific electric resistance of the soil that are much different from the results before the shifting, that can be an indication that there is some metal installation in the earth which, although passive or on zero potential, has a great impact on the distribution of the potential along the surface of the earth, and on the measured specific electric resistance of the earth. The model presented in the paper takes into consideration the existence of such installations and enables to define the regions where the previously specified level of error in measurement of the soil resisitivity ρ should not be exceed. The regions that are to be avoided during measurements can be approximated by ellipses.

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