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A TECHNIQUE OF MEASURING OF RESISTANCE OF A GROUNDING DEVICE

Introduction. Measurement of resistance of the grounding device (GD) by means of a three-electrode system. This requires not only the right choice of installation locations of measuring electrodes, but also the determination of the point of zero potential. Implementation of these requirements quite time-consuming, and in some cases impossible. Aim. Develop a new technique for measuring the electrical resistance of the GD. Task. The method of measuring the resistance of the GD with the help of a three-electrode setup is necessary to exclude the determination of the point of zero potential. Method. Mathematical modeling and calculation engine. Results. A three-electrode system for measuring the resistance of grounding devices (GD) for various purposes is considered. On the basis of Maxwell equations a theoretical substantiation of a new technique for measuring the resistance of any GD of any construction in random soil structure has been proposed. An equation system of the sixth order has been obtained, its solution makes it possible to measure its own mutual resistance in the three-electrode installation with sufficiently high accuracy. Peculiarities of drawing up a calculation scheme of substitution of a three-electrode installation with lumped parameters: self and mutual impedance. Use of the principle of reciprocity eliminates the need of finding a point of zero potential which is a rather difficult task. The technique allows to minimize the spacing of measuring electrodes outside the GD, which substantially reduces the length of wiring of the measurement circuit and increases the «signal-to-interference» ratio and also removes the restrictions on the development of the territory outside the GD being tested. Conclusion. The procedure allows to evaluate the self and mutual impedance grounding all the electrodes in a three-electrode measuring installation of the grounding resistance of the device without finding the point of zero potential. References 12, tables 2, figures 11.

Key words: **grounding device, resistance measurement, three-electrode installation, minimum spacing of measuring electrodes, technique of measuring, substitution circuit.**

Рассмотрена трехэлектродная установка для измерения сопротивления заземляющих устройств (ЗУ) различного назначения. На основе использования системы уравнений Максвелла предложено теоретическое обоснование методики измерения сопротивления ЗУ любой конструкции в произвольной структуре грунта. Получена система уравнений шестого порядка, решение которой позволяет определить собственные и взаимные сопротивления в трехэлектродной установке с достаточно высокой точностью. Рассмотрены особенности составления расчетной схемы замещения трехэлектродной измерительной установки с сосредоточенными параметрами: собственными и взаимными сопротивлениями. Используя принцип взаимности, исключена необходимость отыскания точки нулевого потенциала, представляющего весьма трудоемкую задачу. Методика позволяет обеспечить минимально возможный разнос измерительных электродов за пределами ЗУ, что существенно уменьшает длину соединительных проводов схемы измерения и увеличивает отношение «сигнал–помехи», а также снимает ограничения по застройке территории за пределами исследуемого ЗУ. Библ. 12, табл. 2, рис. 11.

Ключевые слова: **заземляющее устройство, измерение сопротивления, трехэлектродная установка, минимальный разнос измерительных электродов, методика, схема замещения.**

Introduction. Fundamental works of famous scientists: A.L. Vainer [1], S.I. Kostruba [2], A.B. Oslon [3] Iu.V. Tselebrovskii [4], A.I. Yacobs [5], and others deal with problems of measurement of electrical parameters of the earth and grounding devices (GD). In their works domestic and foreign researchers note that one of the main problems is that the exact measurement of resistance of GD for various purposes.

Currently, widespread is a three-electrode measuring device for measuring the resistance of the GD. One of the main problems to be solved to get to this setting, sufficiently accurate results, is as specified in [6], the right choice of places measuring electrode, i.e. correct placement at which the measured value is accompanied electrodes different from its true value by not more than a certain amount, which is called acceptable error of measurement. It is usually assumed that at the measurement of the GD resistance error of about 10% in either direction is acceptable [5].

Measurement of resistances of large GD in a uniform soil is presented in [6] which describes the calculation method defined-division optimal placement of measuring electrodes when measuring resistance of large GD permitting the electrodes placement at short distances by GD. However, it is noted that the calculations with the help of earth considered models have only limited application due to their external fields.

Analysis of Tagg methods for measurement of earth resistance given in [7] showed that Tagg method is not suitable in soils with increasing the depth of soil resistivity.

Besides, in the conclusions of [8] it pointed out that there is a fundamental ability to accurately measure of the GD resistance for any character of the soil heterogeneity and any size and configuration of GD without the use of computational programs which also shows the realization of this possibility. However, unfortunately, in this case it will be necessary to determine the location of the potential electrode by finding the point of zero potential on-site measurements.

Mathematical modeling of the GD resistance measurement process for current of industrial frequency in multilayer soil is presented in [9] which describes an algorithm for calculating the GD resistance measurement errors of electrical installations in multilayer soils at various locations of the measuring electrodes and is an example of building an equal error lines for GD complex shapes in a four-layer ground. Unfortunately, as the authors note [9], choose a layout of electrodes, in which the measured GD resistance equals true, experimentally in measurements on the ground is impossible.

The goal of the work is theoretical substantiation of methods of measuring the GD resistance by means of a three-electrode measuring setup with any character of soil heterogeneity of any size and configuration of GD and the random placement of the measuring electrodes.

Theoretical justification of a developed GD resistance measurement technique. Three-electrode system for measuring the resistance of memory for various purposes in the general case is a multi-electrode system. A calculation of multi-electrode systems in a linear conductive medium of any structure, as noted in [9], based on a system of equations proposed by Maxwell [10].

In this regard, we first consider the example of the calculated equivalent circuit when placing passive grounding in the current field of active GD. Fig. 1 shows the elements of the equivalent circuit: R_1 is the active GD, R_2 is the passive GD, R_{12} is the mutual resistance.

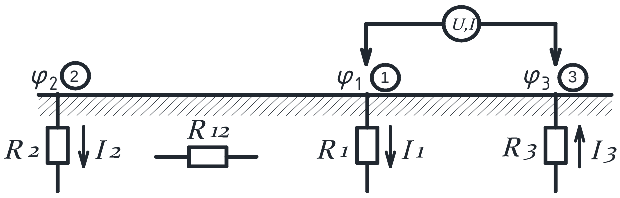

Fig. 1. Mutual influence of active (1) and passive (2) GD

We assume that the current source I_1 has the second pole (R_3), being located so that its field has no effect on the potential at point 2. Potential in point 2 (φ_2) is determined as $I_1 \cdot R_{12}$ then from passive electrode R_2 current I_2 flows into the ground. Source (of current) loaded by additional current I_2; if the source is defined as a «source of voltage», the potential of point 1 (φ_1) is reduced. In the case of «source voltage», power load increases due to the summation of the currents I_1 and I_2. The presence of the two currents (I_1 and I_2) allows the use of already known system Maxwell equations:

$$\begin{cases} \varphi_1 = I_1 R_1 + I_2 R_{12}; \\ \varphi_2 = I_1 R_{12} + I_2 R_2. \end{cases} \tag{1}$$

We note certain limitations in determining the (pilot) of mutual resistance: from the experience of two grounding resistance R_{12} is indefinable. The desire to determine all three resistances is realized when working with a system of three mutually influencing groundings.

Maxwell equations define the potential field communication, whereas to simplify calculations it is more convenient to use the equivalent circuit with some (φ, I, R) parameters.

On the example of two GD streamlined by the same current source (U, I) in a series chain (Fig. 2), consider the options of the equivalent circuit.

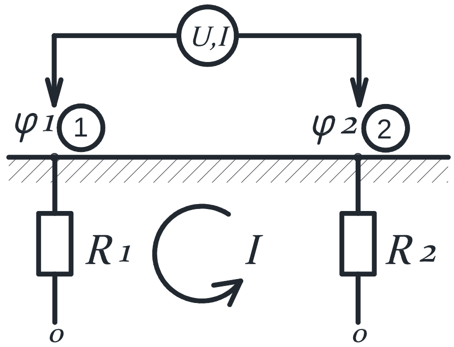

Fig. 2. The system of two GD at their series connection

Following the electrostatic analogy and Maxwell equations we have

$$\begin{cases} \varphi_1 = IR_1 - IR_{12}; \\ \varphi_2 = -IR_{12} + IR_2. \end{cases} \tag{2}$$

On the base of equations (2) we can write

$$\begin{aligned} \varphi_1 + \varphi_2 = U = I\left(R_1 - R_{12} + R_2 - R_{12}\right) = \\ = I\left(R_1 + R_2 - 2R_{12}\right) = IR_{equ}. \end{aligned} \tag{3}$$

Following equation (3) the equivalent circuit has a form (Fig. 3).

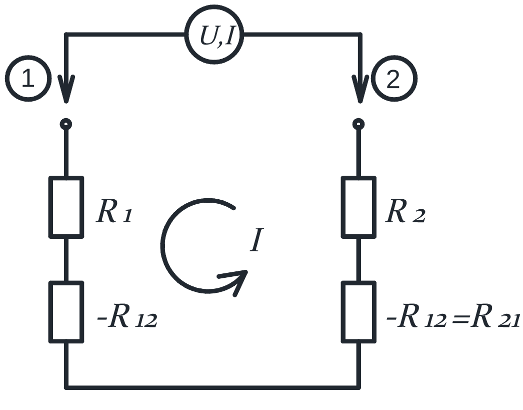

Fig. 3. A variant of the equivalent circuit
for series connected GD

The circuit shown in Fig. 3 is suitable for mathematical modeling, but not for the physical model because of the negative resistances R_{12}. The physical analogue for the circuit in Fig. 3 we present in the form of a diagram on Fig. 4.

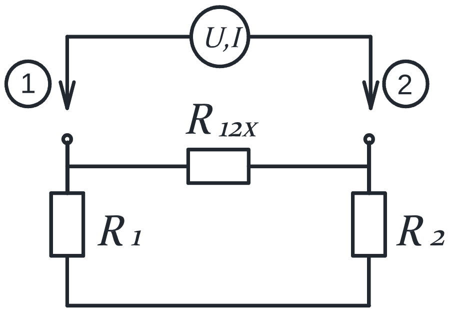

Fig. 4. Calculated analogue of the equivalent circuit

By equality of input resistance of circuit on Fig. 3 and Fig. 4 we have:

$$R_1 + R_2 - 2R_{12} = \frac{(R_1 + R_2)R_{12X}}{R_1 + R_2 + R_{12X}}. \quad (4)$$

After arrangement of summands we obtain

$$2R_{12X}R_{12} = (R_1 + R_2)^2 - 2R_{12}(R_1 + R_2), \quad (5)$$

and from here we obtain

$$R_{12X} = \frac{(R_1 + R_2)^2}{2R_{12}} - R_1 - R_2, \quad (6)$$

or obtain a relation between resistances R_{12} (see formula (5)) and R_{12X}:

$$R_{12} = \frac{(R_1 + R_2)^2}{2(R_1 + R_2 + R_{12X})}. \quad (7)$$

We take into account that mutual resistance R_{12} less than the smaller of resistances R_1 or R_2 and $R_{12X} > 0$.

Using the model for the Fig. 4 in the calculations permits to find the value R_{12X} in view of the expression (7) makes it possible to determine the relative resistance R_{12X}; accounting effect of R_{12} (with the appropriate sign) should be carried out according to Fig. 3.

Measurements at two GD (see Fig. 2) by the input source (U, I) do not allow to decipher the values of R_1, R_2 and R_{12} as well as the potential φ_1 and φ_2. We introduce the third electrode to the point 3, as shown in Fig. 5, and consider three experiments: A, B and C.

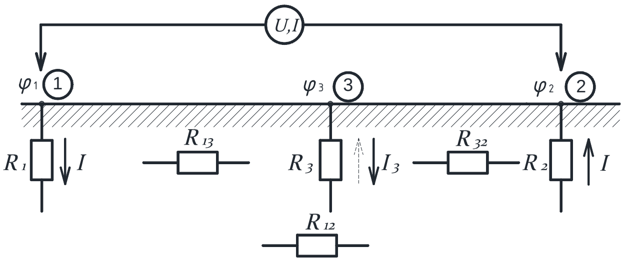

Fig. 5. A three-electrode system of GD, experiment A

In the experiment A the active electrodes 1 and 2, streamlined common current I from the source, create a potential field for the passive electrode 3, which determines the potential of the latter:

$$\varphi_3 = R_{13}I - R_{32}I = I(R_{13} - R_{32}) = IR_{3E}. \quad (8)$$

There are U_{13} and U_{32} voltage. For example, when $U_{32} < U_{13}$ and influence of the electrode 2 on the formation of φ_3 increase over the electrode 1. Under the influence of φ_3 in the electrode 3 the current $I_3 = \varphi_3/R_3$ flows. In the case of $U_{32} < U_{13}$ current I_3 has same direction as the current in resistance R_2; direction of current I in the electrode 1 is assumed positive, and in electrode 2 – negative.

The presence of current I_3 should be considered for active electrodes 1 and 2 through the respective mutual resistance in Maxwell equations. Taking into account the expressions (8) for the active electrode 1, the summand appears

$$-I_3R_{13} = -I\frac{(R_{13} - R_{32})}{R_3}R_{13},$$

and potential of the electrode 1 is determined as

$$\begin{aligned}\varphi_1 &= R_1I - R_{12}I - I\frac{(R_{13} - R_{32})}{R_3}R_{13} = \\ &= I\left[R_1 - R_{12} - \frac{(R_{13} - R_{32})R_{13}}{R_3}\right] = IR_{1E}.\end{aligned} \quad (9)$$

Analogously, we obtain potential for the active electrode 2:

$$\varphi_2 = I\left[R_2 - R_{12} + \frac{(R_{13} - R_{32})R_{32}}{R_3}\right] = IR_{2E}. \quad (10)$$

Potentials φ_1, $\varphi_2$and φ_3 according equations (8), (9) and (10) are expressed by source current I and values of resistors (own R_s (R_1, R_2 and R_3) and mutual R_{vz} ($R_{12} = R_{21}$, $R_{13} = R_{31}$ and $R_{23} = R_{32}$)).

Voltage measurement between passive 3 and active 1 and 2 electrodes determines respectively

$$U_{13} = \varphi_1 - \varphi_3;$$

$$U_{32} = \varphi_3 - \varphi_2.$$

As a result,

$$U_{13} = I(R_{1E} - R_{3E}) \text{ and } \frac{U_{13}}{I} = R_{1E} - R_{3E}, \quad (11)$$

$$U_{32} = I(R_{3E} - R_{2E}) \text{ and } \frac{U_{32}}{I} = R_{3E} - R_{2E}. \quad (12)$$

Voltages measurement U_{13}, U_{32} at current I determines left-hand sides of two coupling equations with six resistors according to (11) and (12).

The next two equations we obtain as measured input current between points 1 and 3. In this case, according to Fig. 6, we consider experiment B.

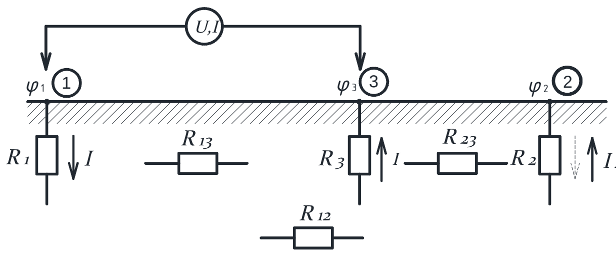

Fig. 6. Connection of the source (U, I) in the experiment B

Voltages U and current I are «own» for this experiment, i.e. they different from the values in the experiment A. Measuring voltages U_{32} and U_{12} allows to determine, for example $U_{32} < U_{12}$ a then to assume current in the resistance R_2 coinciding with the direction of current in the resistance R_3.

For the passive electrode 2 we have potential

$$\varphi_2 = I(R_{23} - R_{12}) = IR_{2E},$$

and flowing from its current

$$I_2 = I\frac{(R_{23} - R_{12})}{R_2}.$$

For the active electrode 1 we determine potential by expression

$$\varphi_1 = I\left[R_1 - R_{13} - \frac{(R_{23} - R_{12})R_{12}}{R_2}\right] = IR_{1E}.$$

Taking into account mutual influences, for active electrode 3 we have potential

$$\varphi_3 = I\left[R_3 - R_{13} + \frac{(R_{23} - R_{12})R_{23}}{R_2}\right] = IR_{3E}.$$

As a result, we obtain voltages available for measurements

$$U_{12} = \varphi_1 - \varphi_2 = I(R_{1E} - R_{2E}) \text{ or } \frac{U_{12}}{I} = (R_{1E} - R_{2E}) \quad (13)$$

and voltages

$$U_{32} = \varphi_3 - \varphi_2 = I(R_{3E} - R_{2E}) \text{ or } \frac{U_{32}}{I} = (R_{3E} - R_{2E}). \quad (14)$$

In the experiment C the source (U, I) is connected between points 3 and 2 as shown in Fig 7.

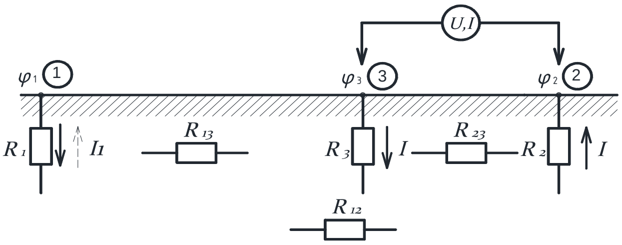

Fig. 7. Connection of the source (U, I) in the experiment C

Measuring voltages U_{13} and U_{12} allows in the case, for example $U_{13} > U_{12}$ assume the potential φ_1 near to potential φ_2 and currents for points 1 and 2 have the same direction.

We express potential of passive electrode 1:

$$\varphi_1 = -IR_{12} + IR_{13} = I(R_{13} - R_{12}) = IR_{E1}.$$

Current I_1 in the resistance R_1 we determine by formula:

$$I_1 = I\frac{(R_{13} - R_{12})}{R_1}.$$

Potentials of active electrodes 3 and 2 are respectively determined by formulae:

$$\varphi_3 = I\left(R_3 - R_{32} - \frac{(R_{13} - R_{12})}{R_1}R_{13}\right) = IR_{E3}$$

and

$$\varphi_2 = I\left(R_2 - R_{32} + \frac{(R_{13} - R_{12})}{R_1}R_{12}\right) = IR_{E2}.$$

Because of in this experiment we measure voltages

$$U_{12} = \varphi_1 - \varphi_2 = I(R_{E1} - R_{E2})$$

and

$$U_{13} = \varphi_1 - \varphi_3 = I(R_{E1} - R_{E3}),$$

then finally we obtain next two equations:

$$\frac{U_{12}}{I} = (R_{E1} - R_{E2}) \quad (15)$$

and

$$\frac{U_{13}}{I} = (R_{E1} - R_{E3}). \quad (16)$$

So, above consideration determines amount of tests (measurements) in three experiments (A, B, C).

Input of the source (U, I) in points 1 and 2 (experiment A) and measuring voltages U_{13A} and U_{32A} at current I_A, gives a possibility to calculate input resistances

$$\frac{U_{13A}}{I_A} = R_{(1-3)A}$$

and

$$\frac{U_{32A}}{I_A} = R_{(3-2)A}.$$

Such resistances are left-hand sides of equations:

- from equations (8), (9) and (11) we obtain

$$R_{(1-3)A} = \left[(R_1 - R_{12}) - \frac{(R_{13} - R_{32})R_{13}}{R_3}\right] - (R_{13} - R_{32}), \quad (17)$$

- from equations (8), (10) and (12):

$$R_{(3-2)A} = \left[(R_2 - R_{12}) + \frac{(R_{13} - R_{32})R_{32}}{R_3}\right] + (R_{32} - R_{13}). \quad (18)$$

Experiment B, input of the source (U, I) in points 1 and 3 and measuring voltages U_{32B} and U_{12B} at current I_B.

Taking into account above-mentioned (expressions (13) and (14)) we obtain

$$R_{(1-2)B} = \frac{U_{12B}}{I_B} = \left[(R_1 - R_{13}) - \frac{(R_{23} - R_{12})R_{12}}{R_2}\right] - (R_{23} - R_{12}); \quad (19)$$

$$R_{(3-2)B} = \frac{U_{32B}}{I_B} = \left[(R_3 - R_{13}) + \frac{(R_{23} - R_{12})R_{23}}{R_2}\right] - (R_{23} - R_{12}). \quad (20)$$

Experiment C, input of the source (U, I) in points 3 and 2, measuring voltages U_{13C} and U_{12C} at current I_C.

Taking into account expression (15) we obtain

$$\frac{U_{12C}}{I_C} = (R_{12} - R_{13}) + \left[R_2 - R_{32} + \frac{(R_{13} - R_{12})R_{12}}{R_1}\right] = R_{(1-2)C}, \quad (21)$$

and from expression (16) we have

$$\frac{U_{13C}}{I_C} = (R_{12} - R_{13}) + \left[R_3 - R_{32} - \frac{(R_{13} - R_{12})R_{13}}{R_1} \right] = \tag{22}$$
$$= R_{(1-3)C}.$$

Finally, we obtain a system of six equations (17) – (22) with six unknowns (R_1, R_2, R_3, R_{12}, R_{13}, R_{23}) at known from measurements resistances values $R_{(1\text{-}3)A}$, $R_{(3\text{-}2)A}$, $R_{(1\text{-}2)B}$, $R_{(3\text{-}2)B}$, $R_{(1\text{-}2)C}$, $R_{(1\text{-}3)C}$.

Solution of the obtained system of six equations with six unknowns is carried out by the code realized in the Mathcad environment.

Some peculiarities of measuring GD resistance. It is useful to add the following to the presented technique. In the case of applying the method to an electrode of zero potential φ_p, for example, a linear circuit «object with R_g – current electrode R_c» and experimentally determined location and potential of the last electrode R_g they achieve the condition

$$\varphi_p = 0 = \alpha_{gp} I - \alpha_{cp} I \tag{23}$$

at series connection of R_g and R_c with source (U, I) – see Fig. 2.

In general case, the potential φ_p by equation (23) is not zero, but there are the potentials of the current I to the electrodes R_g and R_c. Then, if there is some conductivity (to ground) potential electrode when at $\varphi_p \neq 0$ and a current I_p flowing between the electrodes in the circuit voltage dissipated:

$$\begin{cases} \varphi_g - \varphi_p = U_{g-p}; \\ \varphi_c - \varphi_p = U_{c-p}, \end{cases} \tag{24}$$

in accordance with expression

$$\varphi_p = \alpha_{gp} I - \alpha_{cp} I + \alpha_{pp} I_p = U_{g-p} - U_{c-p} + U_p, \tag{25}$$

where α_{pp} is the own potential coefficient of the GD of the potential electrode.

Voltage $U_{g\text{-}p}$ can $U_{c\text{-}p}$ can be measured under the condition of the measuring circuit is negligibly small influence on the current distribution of conductivity in the investigated system (electrodes R_g, R_p and R_c).

At known current I and measured voltage $U_{g\text{-}p}$ by expression

$$U_{g-p} = \alpha_{gp} I, \tag{26}$$

we estimate the value of α_{gp}.

In this system three grounding (Fig. 5) similar to the calculations of the type (26) allow us to determine (based on designations in Fig. 5) mutual resistance R_{12}, R_{13}, R_{23}.

Known values are now possible to consider the mutual resistances for determining own resistances three equations, for example, (17) – (19) or another combination of the equations forming the reciprocal of resistances after introducing in the third order system.

The above approach to the definition of the self and mutual impedances in the case of three of earth is based on the mutual influence of natural elements of earth of a particular group. Great opportunities for research give equivalent circuit and methods of calculation of electrical circuits. It is obvious that communication should form the equation in the case of three GD of the sixth-order equations (the number of mutual and inherent resistance).

Formally, especially solutions of the sixth-order equations can be estimated at solutions for the equivalent circuit with the desired resistors. Estimated scheme (also used for physical modeling) for a group of earth discussed below.

We distinguish for example a group of three GD as shown in Fig. 8.

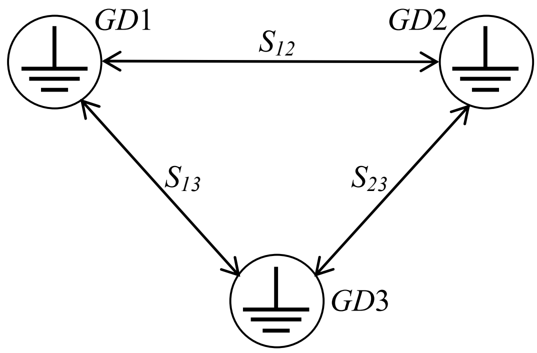

Fig. 8. Placement variant (in plane) of GD group with distances S one from another

Lack of electrical (conductive) links between them necessarily checked.

By definition – every memory can be characterized by some «own» resistance R_s (as if there is no effect of «neighbors») and the effect of the mutual resistance R_{vz}.

By the way, the traditional situation (as reflected in the instructions, guidance documents, and others) of measurement, for example, R_{GD1} is consistent with Fig. 8 at GD2 (or GD3) – current electrode and GD3 (GD2), respectively – potential. Moreover, it is recommended to ensure the lowest possible mutual impedance (in fact – interference) through a search for a comfortable position for GD2 and GD3, either through an increase in distance. Obviously recommendations of RD [11, 12] in their implementation involve estimation of own resistance of GD1.

We will seek to simplify (v. RD) for proper R_{GD1}, namely through the definition of (quantitative) of R_s and R_{vz} in the circuit according to Fig. 8. The proposal removes the requirement to remove the RD current electrode from R_{GD1} (unknown); simplified measurement of their capacity to R_{GD1}.

For three (electrically not connected) GD located in some way in the area (Fig. 8) the use of electrostatic analogy, taking into account the transformations (6) and (7) allows you to submit a design scheme of substitution in the form shown in Fig. 9. We note that the initial measurements are three points accessible: 1, 2, 3.

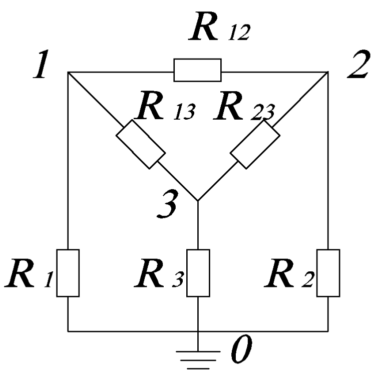

Fig. 9. Calculated equivalent circuit for the group of three GD

Some source (U, e.g. transformer) is connected alternately to the two points of the system and we measure the applied voltage and the voltage of the third point on the two connected to the source. Separate experiments (I, II and III) are shown in Fig. 10 and designated as *a*, *b* and *c* respectively.

The corresponding voltage (U_{12}, U_{13}, U_{32},) in different experiments are different by values.

Under laboratory conditions, the equivalent circuit model is studied (see Fig. 9) with certain parameters, which are shown in Table 1.

Table 1

Resistors values for the circuit on Fig. 9

Resistor	R_1	R_2	R_3	R_{12}	R_{13}	R_{23}
Value, Ω	10	20	5	5	3	3

Results of measurements are presented in Table 2.

Table 2

Measurements of voltages in the equivalent circuit model on Fig. 9 in accordance with Fig. 10

Source connect	U_{12}, V	U_{23}, V	U_{13}, V	φ_1, V	φ_2, V	φ_3, V
Test I, U_{12}	2.75	1.42	1.33	1.18	1.6	0.18
Test II, U_{23}	1.47	2.31	0.83	0.28	1.77	0.55
Test III, U_{13}	1.4	0.82	2.24	1.5	0.09	0.74

Voltages on the «own» resistance measured with respect to the point of «0», designated by the appropriate φ.

The ratios of measured voltage systems are described by systems:

$$\text{Fig. 10,}a \quad \begin{cases} U_{12} = \varphi_1 + \varphi_2; \\ U_{23} = \varphi_2 - \varphi_3; \\ U_{13} = \varphi_1 + \varphi_3; \end{cases} \tag{27}$$

$$\text{Fig. 10,}b \quad \begin{cases} U_{12} = \varphi_2 - \varphi_1; \\ U_{23} = \varphi_2 + \varphi_3; \\ U_{13} = \varphi_1 + \varphi_3; \end{cases} \tag{28}$$

$$\text{Fig. 10,}c \quad \begin{cases} U_{12} = \varphi_1 - \varphi_2; \\ U_{23} = \varphi_2 + \varphi_3; \\ U_{13} = \varphi_1 + \varphi_3. \end{cases} \tag{29}$$

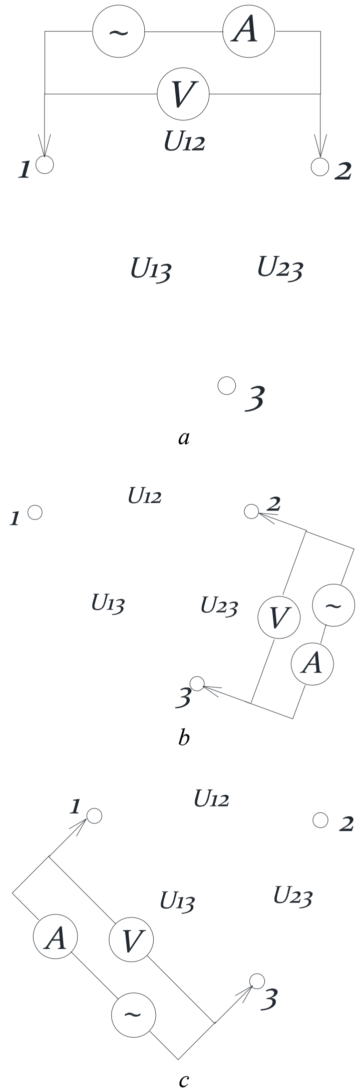

Fig. 10. Connection of the source and measured voltages in the group of GD on Fig. 8

Some equalities in (27) – (29) are satisfied with the approximate measurements of voltages

Formally, the system, for example, (27) has three equations with three unknowns φ_1, φ_2 and φ_3. However, the system is unsolvable by elementary exception of one of unknowns and further solution of two equations with two to remain unknowns.

However, we note that (according to the measurements, calculations) assessment of values φ in systems (27) – (29) is sufficient to obtain the desired resistance of all six unknown resistances (three of their own, the three mutual).

Additional investigations on the territory of the placement of grounding devices GD1, GD2 and GD3 are to remove the gradient curves in an easy direction to connect the variants of Fig. 10. We suppose that t two GD switches at the earth's surface to an applied voltage (Fig. 11,*a*) is formed the U_x potential field, including any and l lines on the surface of earth between the GD edges (Fig. 11,*b*).

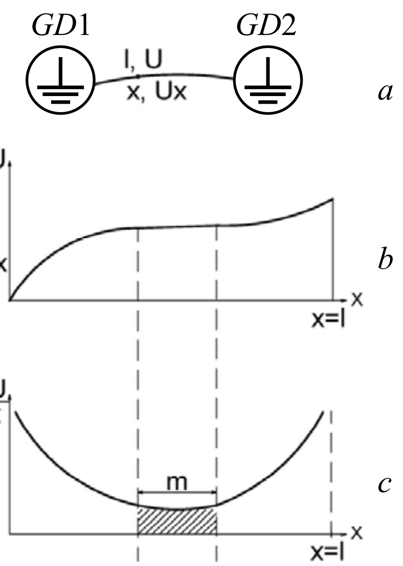

Fig. 11. Potential field between two GD and a gradient curve

The curve (potential) in Fig. 11,*b* corresponds to the gradient curve $\Delta U_x / \Delta x$ (see Fig. 11,*c*). ΔU_x measurements appear to be relatively simple: the input terminals of a voltmeter connected to the electrodes with a length Δx spacing interchanges along the line *l* of the template.

The voltage measured by the voltmeter (one terminal – in the soil at the site *m*, the second (by turn) in point 1 and point 2) assess φ_1 and φ_2. Like the majority of measurements for the GD, the method considered for φ_1, φ_2 is approximate.

Knowledge of φ_1, φ_2 determines the φ_3 value for the system (27); from the values of φ_1 and φ_2 we find φ_1 in (28); from the values of φ_1 and φ_3 we found φ_2 in (29). The subsequent calculation of the possible conductivity (resistance) for the circuit according to Fig. 9 is discussed above.

The code which implements the methodology set out in the paper allows on the basis of the relevant electrical measurements to evaluate not only the resistance of the grounding of electrical devices, but also as its own and mutual resistance grounding all the electrodes in a three-electrode setup measuring the resistance of the grounding device. Also, there is no need to distribute the measuring electrodes longer distances and therefore use large wire length measuring circuit in a three-electrode system. Furthermore, the proposed method is no limitation in the arrangement of the measuring electrodes due to local conditions, even in the case of densely built-up area outside of the investigated GD. Finally, most importantly – there is no need to find the point of ground potential at the measurement electrode or the potential for counting zero error boundaries representing a time-consuming process.

The results of experimental investigations of a three-electrode setup of measuring GD resistance in the electrolytic bath of the National Technical University «Kharkiv Polytechnic Institute» showed that the proposed method provides a fairly accurate results in all cases, measurement of resistance of grounding of electrical devices.

Conclusions.

1. Firstly is a theoretical foundation of the new technique of measuring the resistance of the GD with the help of a three-electrode measuring setup with any character of soil heterogeneity, of any size and configuration of grounding devices and random placement of the measuring electrodes, which, in essence, is universal is presented.

2. On the basis of the investigations carried out it is found that the developed method has the following advantages:

- it permits to evaluate own and mutual resistances of GD of all the electrodes in a three-electrode setup measuring the resistance of the grounding device;
- there is no need for spacing measurement electrodes over long distances in the measuring circuit of a three-electrode unit;
- there are no restrictions in the arrangement of the measuring electrodes due to local conditions, even in the case of dense building areas outside of the investigated GD;
- there is no need for searching the point of zero potential in the place of measuring for the potential or in the calculation of zero error boundary representing a time-consuming process.

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