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GRAPH-ANALYTIC ENGINEERING METHOD OF CORROSION CURRENT CALCULATION IN MULTIELECTRODE SYSTEM

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The calculation methods of corrosion current in multielectrode system have been analysed. The algorithm of graph-analytical engineering method of corrosion current calculation in multielectrode system including the principles of graphic and analytical calculation methods is presented. As an illustrative example the case with three electrodes (copper, iron, and aldrey) is considered.

The main constructional elements of modern installations are concrete and steel structures. Hence, these materials should be in view of investigations on durability of network constructions.

To provide life duration for network constructions and, to greater extent, for designed constructions and ground systems made from them it is necessary to calculate corrosion currents and potentials.

There are analytical, numerical and graphical methods of corrosion current calculations.

Graphical calculation method of corrosive currents consists in analysis of polarization curves (anode and cathode) in the conditions of corrosion and determination of general potential value in corrosive system (U_0). However, given method does not allow for investigation of real construction in laboratory conditions.

By analytical and numerical methods only one kind of corrosion is calculated, usually it is corrosion under the influence of galvanocouple.

Design of operation for each electrode of multielectrode system with any number of electrodes by the analytical method makes two assumptions:

1. If multielectrode galvanic system is a short real-closed in external and internal circuits, the potential of its separate elements levels off at some general potential U_0 due to polarization.
2. If multielectrode system is in stationary condition, i. e. there is no charge accumulation in its separate point in time, the sum of all cathode currents in the system is exactly equal to the sum of all anode currents.

Then, following algorithm of the given method, we set up a system of equations in the form of matrix:

$$\begin{vmatrix} R_{11} & \cdots & R_{1p} & \cdots & R_{1n} & 1 \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ R_{p1} & \cdots & R_{pp} & \cdots & R_{pn} & 1 \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ R_{n1} & \cdots & R_{np} & \cdots & R_{nn} & 1 \\ 1 & 1 & 1 & 1 & 1 & 0 \end{vmatrix} \times \begin{vmatrix} I_1 \\ \cdots \\ I_p \\ \cdots \\ I_n \\ U_0 \end{vmatrix} = \begin{vmatrix} U_1 \\ \cdots \\ U_p \\ \cdots \\ U_n \\ 0 \end{vmatrix}, \quad (1)$$

where: R_{ij} are the characteristic and cross values of cross resistances between *i* and *j* elements; I_j is the cross current, flowing from *j* element; U_0 is the compromise potential of the system of the considered elements connected in «spider»; U_i is the specified (initial) electrode potentials of electric poles (before their connection into system).

Characteristic (*i*=*j*) values of cross resistance are defined in the following way:

$$R_{ii} = R_{ii}^{\Gamma} + R_{ii}^{u} + R_{ii}^{A,K}, \quad (2)$$

where R_{ii}^{Γ} is the metal-base spread resistance; R_{ii}^{u} is the cross resistance of element insulating coating (in its presence); $R_{ii}^{A,K}$ is the polarization resistance (anode and cathode) of the element involved.

In this case the metal-base spread resistance is calculated by the formula:

$$R_{ii}^{\Gamma} = \frac{1}{2}\frac{\rho}{\pi \Gamma}\ln\frac{4l}{d}, \quad (3)$$

where ρ is the base specific resistance; Γ is the main (largest) size of ground, m; l is the vertical ground length, m; d is the vertical ground diameter, m.

Difficulty in solution of the considered equation system and, hence, difficulty in calculation method consists in determination of polarization resistance type (anode or cathode) of the elements connected in system.

Indeed, the sign of cross current I_j («plus» is for cathode, «minus» is for anode) defines the value of polarization resistance, since the values of R_{ii}^{A} and R_{ii}^{K} can be sufficiently different from each other. Besides, the value $R_{ii}^{A,K}$ is a prevailing one with regard to the resistance R_{ii}^{Γ}, which is crucial in absence of element insulating coating (R_{ii}^{u}).

To determine approximately the character of polarization for the considered elements preliminary analysis of equation system is to be carried out: matrix is to be transformed and some «*p*» equation is to be excluded from the system by subtracting it from other equations. Thus, we obtain the auxiliary equation system, by the right part the polarization character is judged: at positive potential difference cathode resistance is used R_{ii}^{K}, at negative one – that of anode R_{ii}^{A}. In such a way all elements of the system involved are analyzed except the elements with maximum and minimal values (the sign is taken into account) of electrode potential, as the first is always anode, and the second one is cathode.

Having determined the approximate character of all element polarization in construction and according to this having included the required polarization resistance $R_{ii}^{A,K}$, we solve the initial equation system relative to carrion currents and compromise potential. Comparing the signs of the corrosion currents obtained with the results of preliminary determination of polarization type, we see their agreement. In case of sign disagreement for separate elements their type of polarization is changed according to the result of the last calculation, this calculation being repeated to complete agreement in signs of corrosion currents of the last and previous calculation data, i. e. iteration process is started.

Application of iteration solution often results in iteration disagreement due to many-valuedness of the problem solved.

The disadvantages of the given method can be avoided, if one develops some general method including positive features of graphical and analytical methods, the so-called graph-analytical engineering method.

Let us give the algorithm of method.

1. Construct «current value – potential» polarization diagram. On one diagram plot anode and cathode polarization curves for the conditions interesting for us (anode and cathode polarization curves are usually obtained in independent experiments on polarization from external power supply), reconstructing them in such a way that not current density *i* is plotted on abscissa axis as it was in polarization curve design, but current value *I* is. In Fig. 1 such diagram is schematically presented for five-electrode system. Here U_1, U_2, U_3, U_4, U_5 are stationary electrode potentials of separate system constituents in the corrosion conditions (for electrodes 1, 2, 3, 4, 5 respectively) without current flow. There are the curves of anode polarization (U_1A_1–U_5A_5), the curves of cathode polarization (U_1K_1–U_5K_5).

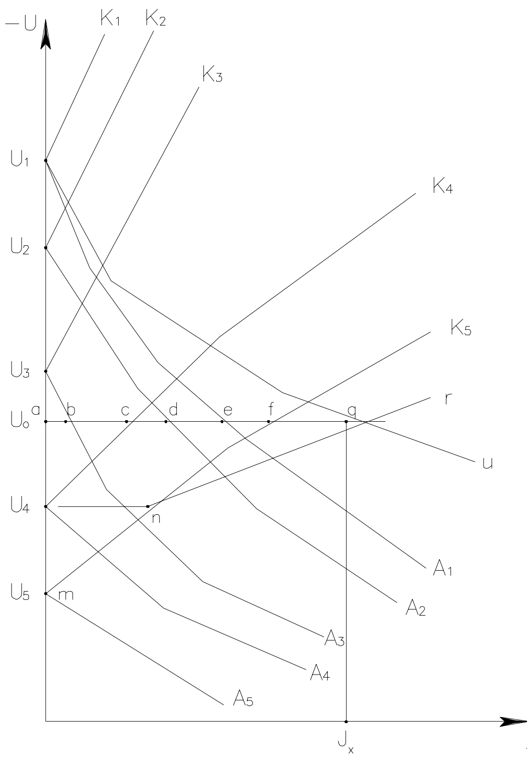

Fig. 1. *Graphic calculation of multielectrode system on the basis of real multielectrode curves*

2. Plot the summary curves of anode and cathode polarization on the diagram. The summary curves of anode (stqu) and cathode (mnqr) polarisations are produced by simple addition of current values of all anode processes for each potential between U_1 and U_5, and hence, current values of all cathode processes for the same potential path. This diagram characterizes the current values for each system electrode depending on general potential in the system. This general potential of multi-electrode system (U_0) equals to potential, at which the sum of all system cathode currents equals to the sum of all anode currents.
3. Determine the conditions (anode or cathode) of every electrode operation in multi-electrode system. Abscissa values of cross points of anode and cathode polarization curves with the line U_0q parallel to abscissa axis give the current direction and value in each system electrode. In the given example the cathode polarization curves of electrode 4 and 5 cross the line U_0q, hence, these electrode operate by the cathode, in this case the value of cathode current on them is consequently proportional to segments *ac* and *af.*

For electrodes 1, 2, and 3 the U_0–q line is crossed by anode polarization curve. Consequently, electrodes 1, 2 and 3 operate by anodes in the given system, in so doing anode current values are correspondingly determined by the values of the segments *ae*, *ad* and *ab*. It is seen from the diagram that anode polarization curve for the most positive electrode and cathode polarization curve for the most negative electrode are redundant for this diagram, as they cannot be summed up with anode and cathode polarization curves correspondingly in the U_1 and U_0 potential path.

4. Set up the equation system in the form of matrix (1). To generate the equation system it is necessary to define self and mutual electrode resistances. Proper values of cross resistance are calculated by the formula 2. Since proper values R_{ii} of cross resistances exceed essentially their mutual values R_{ij}, we take the latter as equal to zero to simplify the calculation.
5. Solve the equation system (1) relative to unknown corrosion currents and system compromise potential.

Let us consider the method behaviour for corrosion current calculation by the example of three electrodes: copper (Cu), iron (Fe), and aldrey (Pl). Radius of electrode cross section is r_{el}=0,3 sm, length of the first two electrodes L_{el}=4,0 sm and the third is L_{el}=3,5 sm. All electrodes were placed in a box and partly exposed to day surface, being at the distance of *d*=7 sm from each other, i. e. on the vertexes of equilateral triangle. Proper values of spread resistance for these electrodes amounted R_{el}^r=120 Om for the first two electrodes, but for the third one is R_{el}^r=131 Om. Specific resistance (of box filler) amounted approximately $\rho_r \approx 10$ Om·m.

In Fig. 2 polarization curves of the electrodes involved (the Evance diagram) are presented. Their electrode potentials were: U_{Cu}=–0,112 V, U_{Fe}=–0,525 V and U_{Pl}=–0,970 V. Anode (Cu^A, Fe^A, Pl^A) and cathode (Cu^K, Fe^K, Pl^K) polarization curves of the electrodes involved are shown in Fig. 2 by dashed line. Accumulation curve of polarization and spread resistance for considered electrodes are depicted in Fig. 2 in the form of full line. From the presented diagram we determine the conditions of electrode operation: Pl electrodes played the part of anode, only anode accumulation curve is plotted for it, but Cu electrode appeared to be cathode, only cathode curve is shown for it, Fe electrode is an anode with respect to the other electrodes.

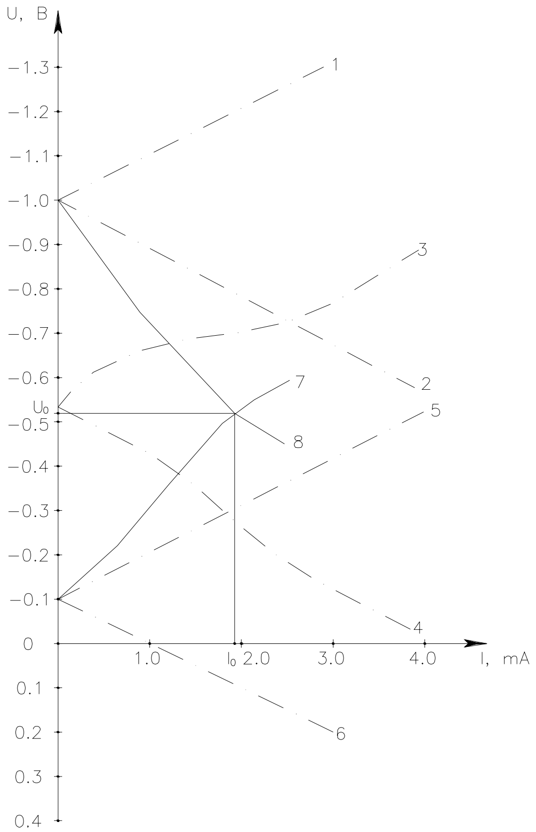

Fig. 2. *The Evance diagram*

Thus, from the diagram we find anode resistance for Pl and Fe electrodes, as well as cathode resistance for Cu electrode.

According to the algorithm, the next step is determinations of proper value of electrode cross resistance by the formula (2), we obtain: Om, Om, Om.

Then we set up the equation set and present it in the form of matrixes:

$$\begin{vmatrix} 181 & 0 & 0 & 1 \\ 0 & 215 & 0 & 1 \\ 0 & 0 & 239 & 1 \\ 1 & 1 & 1 & 0 \end{vmatrix} \times \begin{vmatrix} I_{\text{Cu}} \\ I_{\text{Fe}} \\ I_{\text{Pl}} \\ U_0 \end{vmatrix} = \begin{vmatrix} -0,211 \\ -0,525 \\ -0,970 \\ 0 \end{vmatrix}.$$

The solution for the set of equations is the following matrix:

$$\begin{vmatrix} I_{\text{Cu}} = 2,12 \text{ мA} \\ I_{\text{Fe}} = -0,16 \text{ мA} \\ I_{\text{Pl}} = -1,96 \text{ мA} \\ U_0 = -0,511 \text{ B} \end{vmatrix}.$$

Now let us try to trace the influence of four time increase in cathode square on corrosion process, i. e. L_{Cu}=16,0 sm. Then R^{r}_{Cu}=108 Om. The set of equations has the following view:

$$\begin{vmatrix} 108 & 0 & 0 & 1 \\ 0 & 215 & 0 & 1 \\ 0 & 0 & 239 & 1 \\ 1 & 1 & 1 & 0 \end{vmatrix} \times \begin{vmatrix} I_{\text{Cu}} \\ I_{\text{Fe}} \\ I_{\text{Pl}} \\ U_0 \end{vmatrix} = \begin{vmatrix} -0,211 \\ -0,525 \\ -0,970 \\ 0 \end{vmatrix}.$$

The solution for the given system is the matrix:

$$\begin{vmatrix} I_{\text{Cu}} = 2,11 \text{ мA} \\ I_{\text{Fe}} = -0,31 \text{ мA} \\ I_{\text{Pl}} = -1,80 \text{ мA} \\ U_0 = -0,408 \text{ B} \end{vmatrix}.$$

The results of calculation show that increase in square of, for example, cathode by a factor of four, leads to 2 times increase in anode current of iron. This conclusion is of practical value. For example, extension of operating substation results in changing corrosive conditions in grounding system which is necessary to take into account in designing substation reconstruction. In similar way we can trace the changes in corrosion currents and compromise potential of the system at changes of specific medium resistance, i. e. at changes in corrosion conditions.

Conclusion: Universal method of corrosion current calculation permitting for sufficiently exact determination of operation conditions for each of electrodes in multielectrode system as well as tracing the way of influencing the change in electrode sizes and conditions of the system on corrosion processes has been obtained.

REFERENCES

1. Demin Yu.V., Demina R.Yu., Gorelov V.P. Provision of duration for network materials and constructions in corrosive medium: in 2 parts. Part 1. Theoretical bases / Yu.V. Demin, R.Yu. Demina, V.P. Gorelov; Edited by V.P. Gorelov. – Novosibirsk: Novosibirsk State Academy of Water Transport, 1998. – 209 p.
2. Karyakin R.N. Ground grids of electric installation: reference book / R.N. Karyakin. – Moscow: Energoservice, 1998. – 376 p.
3. Tomashov N.D. Theory of corrosion and metal protection / N.D. Tomashov. – Moscow: AS of USSR, 1959. – 600 p.

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