Main trends in increasing technical and economic efficiency of underground power pipelines cathodic protection

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Abstract. The analysis and systematization of the main factors determining the parameters of the electrochemical protection of underground metal communications (UMC) is carried out in the article. Reasons influencing current consumption and power losses in the DC circuit of the cathodic corrosion protection are discussed in detail, and practical recommendations for their reduction are given. Preparatory measures have a significant impact on anticorrosive protection of power pipelines, namely, measures to improve the quality of insulation (increasing the electrical resistance of coatings and ensuring their integrity), measures to ensure high longitudinal conductivity of pipelines, and removal of contacts of underground metal structures with other earthed structures. On the basis of the research, practical recommendations for reducing power losses and reducing current consumption in cathodic protection systems are given.

Statement of the problem
Corrosion resistance plays a significant role in energy objects design, construction and operation [1, 2, 3]. Since protection from corrosion is not only technical but also an economic problem, it is essential to take into consideration costs of specific anticorrosive measures. Chosen method of corrosion protection largely determines the reliability of power equipment operating under aggressive conditions. Due to this, measures of increasing reliability and reducing costs of combined anticorrosion protection for underground metal communications are of special importance and will be studied in this article from the perspective of their technical and economic efficiency.

Evaluation of technical and economic efficiency of combined anticorrosive protection of UMC
In accordance with GOST 9.602 - 2005 and GOST R 51164 - 98, the criterion for the technical effectiveness of combined corrosion protection, which includes both protective anticorrosive coating and electrochemical protection (ECP), is the fulfillment of two groups of requirements:
• Requirements for the protective coating (quality of anticorrosive materials, coating technologies, properties of the finished coating);
• Requirements for the value of the protective potential without its ohmic component, which, as a rule, should be in the range from (-0.85) volts to (-1.15) volts over the copper-sulfate reference electrode during the whole service life of the object.
Within the framework of this article, we will assume that the specified technical conditions are certainly fulfilled. And, therefore, the main problem of evaluating the economic effectiveness of combined corrosion protection is the problem of optimizing the parameters of electrochemical protection, as the assessment of the economic efficiency of coatings is usually not difficult, and these data is easily accessible in the specialized literature. This approach allows us to consider the work done by the cathodic protection system to achieve the polarization potential as "useful work", that is, the work done to shift the potential of the structure from its corrosion potential $\phi_k$ to its protective potential $\phi_p$ without an ohmic component. In this case, all other costs associated with the passage of an electric current during cathodic protection of UMCs can be attributed to losses that are expediently divided into the following five groups:

- Losses associated with the conversion of an alternating current into a direct current.
- Losses associated with an excessively high protective potential of UMS, caused by insufficient protective potential adjustment system efficiency.
- Losses in the circuit of an alternating (supply) current line.
- Losses in the protective current circuit.
- Losses due to the low level of measures to reduce the protective current at UMC.

Let us look at the mentioned above losses in more detail.

The first two types of losses are closely related to the current state of the equipment in the field of direct current sources for cathodic protection and protective potential adjustment systems that are mainly determined by the market of the corresponding products. Therefore, their influence on the economic efficiency of ECP under specific design conditions is relatively simple and does not require special consideration. The third type of losses is largely determined by the interposition of UMCs and alternating current sources and, therefore, it is impossible to take them into consideration without corresponding data. On the other hand, when the required data is available, it is quite easy to calculate losses in the power line for the economic efficiency of cathodic protection, and therefore, due to the limited volume of the article, its analysis is not given here. Since losses of fourth and fifth type have a significantly greater impact on the level of costs of cathodic protection systems' construction and operation we will analyze them in more detail.

### Losses in the protective current circuit and main ways to reduce them

Analysis of the processes taking place in the protective current circuit has recently received a lot of attention. In this case, various methods [4] are applied, including the method using the following formula [5]:

$$E = (E_a - E_k) + |\eta_a| + |\eta_k| + E_{3-\tau} + E_{\text{cont}} + E_{\text{con wire}}$$  \(1\)

where, $E$ – is output voltage of the cathodic protection converter, $E_a$ – stationary anodic ground potential, $E_k$ – stationary potential of the protected structure. $|\eta_a|$ and $|\eta_k|$ – are, respectively, absolute values of anodic and cathodic overvoltage. $E_{3-\tau}$ – voltage drop on the electrolyte resistance. $E_{\text{cont}}$ – voltage drop across the contacts in the DC circuit. $E_{\text{con wire}}$. - voltage drop on the connecting wires (cables) of the DC circuit.

We will briefly analyze the effect of the individual components of formula (1) on the magnitude of losses in the DC circuit:

1. The effect of the $(E_a - E_k)$ value

   $E_a$ and $E_k$, are determined by the specific corrosion conditions of the anodic earthing and underground metal structure (UMS). The oscillations of these quantities usually amount to several tenths of one volt [6], and the currents flowing in the DC circuit are extremely small, which leads to an extremely insignificant effect of these parameters on the value of the power loss in the DC circuit.

2. The effect of anode overvoltage $\eta_a$. 


Practical measurements [7] carried out at UMC cathodic protection in the ground show a potential drop in the range from one to two volts due to electrochemical process deceleration at an anode grounding. This value is quite large and measures should be applied to reduce it.

3. The effect of cathodic overvoltage $\eta_k$.

If, in order to minimize power losses associated with anode overvoltage, it is required to reduce, then to solve the same problem in the protective current circuit, in contrast to anodic polarization, for the quantity $\eta_k$, on the contrary, maximum growth is required with a possible small protective current [7]. In this case, the increase in power losses due to the actual cathodic polarization of the protected structure is more than compensated by the energy gain at other resistances in the DC circuit.

4. The effect of voltage drop at the contacts $E_{cont}$ in the DC circuit.

It is known from practice that the voltage drop at all contacts in the DC circuit is usually limited to 0.05 volts. However, this drop in the potential at high protection currents can cause power losses of up to 5 watts or more, which, if the quality of the connections deteriorates, can lead to catastrophic failure of ECP systems.

5. The effect of the voltage drop at the connecting wires (cables) $E_{con,wire}$ in the DC circuit.

The length of the connecting wires in the DC circuit is determined by the geometry of the site on which the ECP system should be located and the possible harmful effect of the cathodic protection system on adjacent underground metal structures. To reduce power losses, the length of the wires (cable) under these conditions should be minimized. The choice of the optimal cross-section of the DC cable is usually performed using a special graph (see, for example, reference [4]), based on the value of the protective current, the type of cable and the life of the electrochemical protection unit or the maximum permissible voltage drop on it, should not exceed two volts.

6. The effect of voltage drop in electrolyte $E_{electrolyte}$.

Traditional electrochemical protection systems are characterized by such an arrangement of protected UMCs and anode groundings, where from the point of view of ohmic resistance between them it can be considered, that they are at an infinite distance from each other. Then, for the total resistance of the electrolyte $R_{3-T}$, we can write the following formula:

$$R_{3-T} = R_T + R_A$$

(2)

It immediately follows that the change in the value of $R_{3-T}$ is due, to changes in the parameters of the anodic grounding and the pipeline. Therefore, this analysis can be carried out separately, for each of these objects. Then the total power loss [8] at the ohmic resistance of the anode ground, $P_a$, with the optimal number of anodes $n_a$, will be:

$$P_k = I_s^2 \frac{R_a}{n_a} F \frac{\rho}{\rho_0}$$

(3)

where, $F$ – an interference factor of the anodes, which determines the increase in the resistance of the anode device as a result of mutual screening of individual anodes; $\rho$ – soil resistivity in the area of anodic earthing; $R_0$ – resistance to spreading of a single anode, with specific resistivity of the ground $\rho_0$, equal to 10 $\Omega \cdot m$; $I_s$ – protective current.

Along with already mentioned methods of estimating power losses on various elements of the ECP system, measures to limit the amount of protective current on the protected object [9] are of great importance as well. Their implementation dramatically reduces the consumption of electric current per unit of the protected surface.
Conclusions

- This article presents the analysis and systematization of the main factors affecting ECP system current consumption and power loss while applying UMC cathodic protection against corrosion.
- The main factors affecting current consumption and power loss in the DC circuit of the ECP system are systematized and described in detail.

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