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INFLUENCE OF THE PROTECTIVE POTENTIAL DISTRIBUTION OF A STEEL UNDERGROUND PIPELINE ON ELECTROCHEMICAL CORROSION PROCESSES

Purpose. To distinguish the influence of inserts, with high resistance to the flow of electric current, which causes deviations of the protective potential along the length of the pipeline from its classical form. Obtaining analytical dependencies in the form of a transfer function that relates the input and output signal. That allows predicting dangerous deviations of the protective potential, the combination of which indicates a worsening of corrosion protection.

Methodology. To achieve this purpose, the methods of theoretical analysis, mathematical and computer modeling, and spectral analysis of signals are used. The initial information characterizing the operating modes of adjacent cathode stations is obtained and verified based on the data from monitoring the protective potential along the tracks of underground steel pipelines of various designs. The parameters taken into account in the calculations include the geometric dimensions of the pipeline, soil condition, insulation resistance, etc. By analyzing the results of measurements obtained with the help of a recording voltmeter “PRIMA 2000” and a detector “Sprut-17”, the growth of corrosion risks arising from the repair of a damaged section of an underground steel pipeline using polyethylene pipes is established and analyzed in detail.

Findings. A modeling of the operating modes of adjacent cathodic protection stations, between which there is a section of polyethylene pipeline, with the electrical parameters of an underground steel pipeline is performed. Based on the information obtained, attention is drawn to possible rational energy operation modes of adjacent cathodic protection stations, the main task of which is to reduce the corrosive effects of the polyethylene section of the underground pipeline.

Originality. The paper is to substantiate the possibility of such a negative impact of a polyethylene insert in a steel pipeline, which increases the corrosion hazard. The dependence is obtained of the protective potential of cathodic protection stations in sections of the pipeline with polyethylene inserts from the operating modes of the electrical system with energy converters and their voltage generation algorithms at the output of cathodic protection stations.

Practical value. The paper analyzes the signals of rectifiers of cathodic protection stations and power switches commutation modes that are aimed at improvement of the complex corrosion situation on low and medium pressure pipelines, which are characterized by heterogeneity of structure, especially within populated areas. The proposed modes of operation of adjacent cathodic protection stations reduce the level of corrosion hazard caused by the massive introduction of polyethylene pipes and their widespread use for repairing damaged sections of steel pipelines.

Keywords: *underground steel pipeline, cathodic protection, electrochemical corrosion, electrical parameters of the pipeline*

Introduction. Ukraine’s gas transportation system (GTS) is of strategic importance for the development of industries and the sustainability of Ukraine’s economy. The GTS ensures safe and stable transportation of natural gas from gas storage facilities, production and import areas, to various consumers, which is important for the

operation of industrial enterprises, production of heat and electricity, and for household needs. Its uninterrupted operation plays a key role in ensuring the country’s energy security.

Ukraine’s gas transportation system in terms of the length of main pipelines is one of the longest and most extensive networks among European countries (about 33.2 thousand kilometers) and is second only to Germany’s (about 40 thousand kilometers) [1]. The Ukrai-

nian GTS is integrated into the pan-European network through close connections with the gas systems of neighboring countries. Domestic consumers in the household and industrial sectors are supplied with natural gas through the gas distribution network (GDN) system, which is also one of the largest in Europe and, according to the NCREPU, reaches about 290 thousand km [2].

Ukraine's active position on low-carbon development and green transition [3] affects the gas supply sector and puts forward requirements for modernization and development of the system. The Ukrainian Gas Transportation System faces many organizational, regulatory, and technological challenges, such as depletion of fields, import dependence, reduced transit volumes, distribution losses, low investment, etc. [4]. Nevertheless, it must ensure reliable, uninterrupted and secure gas supplies, which is an important and challenging task due to the outdated infrastructure.

Ukraine's GTS consists of main pipeline network and compressor stations that transport gas under high pressure, and gas distribution networks and stations that transport and distribute gas to consumption facilities.

The gas distribution system is an industrial complex for the transportation of natural gas from the main gas pipeline to consumers. It includes gas distribution stations, gas distribution points and gas distribution networks, as well as high, medium and low pressure gas pipelines. Gas is supplied to high-pressure gas distribution networks (from 0.3 to 0.6 MPa and from 0.6 to 1.2 MPa) from the main gas pipeline through a gas distribution station, and to medium-pressure (from 0.005 to 0.3 MPa) and low-pressure (up to 0.005 MPa) gas distribution networks through gas distribution points [5].

The vast majority of Ukraine's gas distribution network is represented by the underground steel pipeline transportation system. They are characterized by high mechanical resistance to geotectonic ground shifts and a long service lifetime, which is critical for ensuring uninterrupted gas transportation. On the other hand, steel pipelines are highly susceptible to electrochemical corrosion, which is characterized by the loss of metal from the structure to the surrounding electrolyte, which is the soil around the pipeline.

However, as the quality of polyethylene pipes has improved, the practice of using them in gas distribution networks has become widespread [6]. The advantages of these pipelines include the absence of electrochemical corrosion, and therefore the need for additional pipe insulation. Modern polyethylene pipelines have a service lifetime of more than 50 years. However, a simultaneous transition to polyethylene pipelines is not possible due to technical and economic constraints (high cost of work and time required for its implementation).

When carrying out repair and maintenance activities aimed to ensure the integrity of underground steel gas pipelines and extend their operational characteristics, specialized organizations carry out repair work, which, among other things, involves replacing a part of the steel pipeline with a polyethylene one [7]. The presence of such inserts, the electrical conductivity parameters of which differ significantly from those of the steel pipeline material, causes distortion, significant deviation, and a change in the nature of the po-

tential value along the pipeline from the generally accepted one.

In the context of these challenges, this paper focuses on aspects of the operation of two adjacent cathodic protection stations, in the common zone of influence of which, as a result of maintenance activities, a section of polyethylene pipeline appeared. To ensure long-term operational characteristics of the pipeline, the operating modes of the CPSs must take into account the nature of the deviation of the protective potential's dependence formed by adjacent CPS.

Purpose. Typically, on a homogeneous underground steel pipeline, the protective potential from the connection points of the cathodic protection station decreases smoothly according to an exponential law (Fig. 1). The cathodic protection stations distributed over the distance of the pipeline provide a value of the polarization potential of the metal in the range from -0.85 to -1.15 V relative to the saturated copper sulfate anode electrode [7].

On the other hand, among the 290 thousand kilometers of gas distribution pipelines, a significant part has been in operation for more than 50 years (according to surveys, it is not surprising to find gas pipelines laid in the 50s and 60s of the last century). In the course of operation, such pipelines, due to damage to insulating coatings, delamination and cracking, as well as repair and restoration activities, form areas with different electrical parameters from the original ones. To ensure reliable electrochemical protection of the damaged area, there is no option but to further reduce the protective potential compared to the standard. As a result, the following undesirable effects are formed:

- excessive protection of undamaged sections of the pipeline;
- risks of damage to the remaining insulation;
- irrational power consumption by the cathodic protection station;
- excessive loss of protective anode material.

All of these factors have a direct negative impact on the operational and economic qualities of the CPS.

Corrosion processes depend on internal and external conditions. Internal factors of electrochemical corrosion include the nature of the metal, its surface condition, crystal structure, structural defects and stresses. External factors include the characteristics of the corrosive environment, including such parameters as the level of hydrogen ion activity (pH), composition and concentration of solutions, electrolyte velocity, temperature, pressure, contact with other metals, ultrasound, irradiation, external and stray currents, and other similar factors.

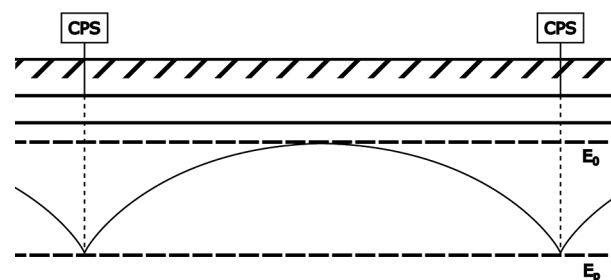


Fig. 1. Diagram of the protective potential distribution along the underground pipeline in the influence zone of two adjacent CPSs

When considering a section of an underground steel pipeline that has a clearly defined difference in electrical parameters from neighboring sections, two opposite cases can be considered:

1. Poor condition of insulation coatings, with direct contact with the ground.
2. An insert of polyethylene pipe, the electrical resistance of which is orders of magnitude higher than the neighboring sections.

In the first case, the power consumed by the section for electrochemical protection begins to grow rapidly, and its effectiveness decreases. As a result, maintaining the protective potential for active protection of such a section loses all meaning and the pipeline requires major repairs.

In the case of repairing a damaged underground steel pipeline using polyethylene pipes, in the area of operation of two adjacent cathodic protection stations, the measurement data demonstrates an area of high probable corrosion risks that must be taken into account.

Regulatory documents governing the standards for the design of electrical protection systems [7] emphasize the danger of soil corrosion activity against the pipeline material and the impact of direct and alternating stray currents.

In the case of an underground steel pipeline, part of which has been restored using a polyethylene section located at the same distance from two adjacent cathodic protection stations, a significant heterogeneity appears in the current flow circuit through the pipeline to the cathodic protection station (Fig. 2, point *A* or *B*), which may differ in electrical parameters from the surrounding sections by orders of magnitude.

Since modern cathodic protection stations use rectifiers as a source of direct current, the output signals of which are usually high-frequency electrical pulses [8], the pipeline can be considered as a cable line. Similarly, to the probing pulses during cable reflectometry, the pulses from the cathodic protection station are reflected from the inhomogeneities in the line and returned to the source. From the point of view of electrochemical protection of an underground steel pipeline, the reflected pulses distort the spectrum of the original signal and, accordingly, provoke electrochemical corrosion.

It is also crucial to understand that this pattern is symmetrical on the other side of the polyethylene pipeline section, as the same thing happens with the pulses from the second cathodic protection station [9]. As a result, at both ends of the polyethylene pipeline section, a part of the cathodic protection station's pulses is re-

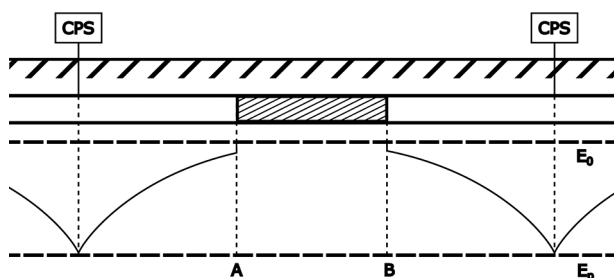


Fig. 2. Diagram of the distribution of protective potential along an underground pipeline with a polyethylene insert in the zone of influence of two adjacent CPSs

flected, and therefore the neighboring steel sections are in increased corrosion danger.

It was also noted above that the polyethylene insert has a significant difference in resistance relative to neighboring, conditionally homogeneous, sections of the steel pipeline. As a result, there is a sharp change in the level of protective potential at points *A* and *B*, which previously decreased smoothly due to the low resistance in the cross-section of the steel pipeline (Fig. 2).

Polyethylene pipes can be connected to other pipe materials using compression fittings, flanges, or other qualified connection types with or without welding [10]. Since the potentials of points *A* and *B* are not the same, a potential difference is formed at the junction of the polyethylene and steel pipeline, which leads to the formation of current and, consequently, the appearance of a secondary stray current generator. As a result, the material is carried away at the joint by the current, which is especially dangerous in the welding area.

External alternating current can be particularly dangerous for an underground steel pipeline, as it can lead to accelerated corrosion of the steel, which can cause pipeline failure [7, 11]. This can happen if the average negative potential displacement reaches values of 10 mV or more compared to the steady-state potential or if the AC density at the auxiliary electrode exceeds 1 mA/cm² (or 10 A/m²). This can lead to serious consequences, including fluid leakage, equipment damage, and even catastrophic accidents [7].

It must also be taken into account that since the polyethylene insert is located between two adjacent cathodic protection stations, a potential jump is observed at both ends of the insert. A possible solution to this problem is to equalize the potential, for example, by electrically connecting the steel sections of the pipeline using a conductor. However, such a solution is not rational because the shunt conductor is current-carrying, which means it is also susceptible to electrochemical corrosion, and therefore it requires protection, otherwise it will deteriorate much faster than the pipeline. Most regulatory documents do not recommend shunting as a means of potential equalization.

Methods. The total power consumed by the CPS and transmitted to the pipeline is the sum of two components: the power consumed to generate external currents flowing from the anode through the soil, which play a key role in the electrochemical protection of the pipeline, and the power consumed by currents flowing through the pipeline itself, the so-called equalization currents. Their appearance is the result of the uncoordinated operation of adjacent cathodic protection stations (Fig. 3).

In the absence of corrosion processes, i.e. in the absence of current, both powers would be equal to 0. Since there is always imperfection in the insulation coating

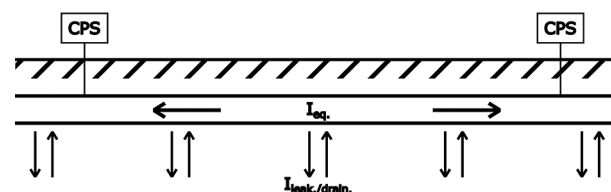


Fig. 3. Currents in the underground pipeline

and coordinated operation of adjacent stations, this state cannot be achieved. However, the ratio of these components in the total power of the CPS is important. Since the source of equalizing currents is adjacent cathodic protection stations, the negative impact can be minimized by synchronizing the operating modes. The real danger to the underground pipeline is the currents flowing into and out of the pipeline, and therefore minimizing the associated power is a key element of successful electrochemical protection.

To determine the quality of the pipeline electrochemical protection system along its length, certain assumptions are made about the protective current density, i. e. the ratio of the polarization current strength to the surface area. However, the presence of alternating current density is a corrosion factor. One and the same drainage current can be either evenly distributed throughout the pipeline or concentrated in one point of insulation damage. And even a small current of 4.5 μA flowing from the pipeline is sufficient to carry out a mass of metal per year, equivalent to a through hole of 1 mm^2 .

To confirm these corrosive effects of polyethylene inserts and verify the need to optimize the operation modes of cathodic protection stations, analytical [12, 13], mathematical [14] and computer modeling [15, 16] methods are used.

Equivalent circuit. Equivalent circuit of an underground steel pipeline section with concentrated parameters. In the course of the study, the pipeline section is described as an object with concentrated parameters (Fig. 4).

In Fig. 4, R_p , L_p are the resistance and inductance of the pipeline; R_{in} , C_{in} are the resistance and capacitance of the insulation; R_g is the resistance of the soil. Resistance, inductance of the pipeline and insulation capaci-

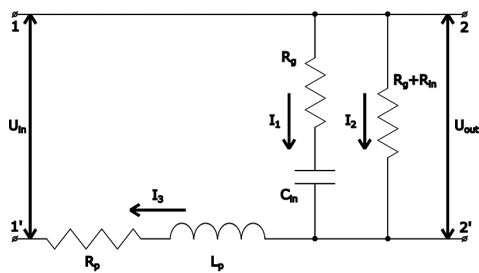


Fig. 4. Equivalent circuit of an underground steel pipeline with concentrated parameters

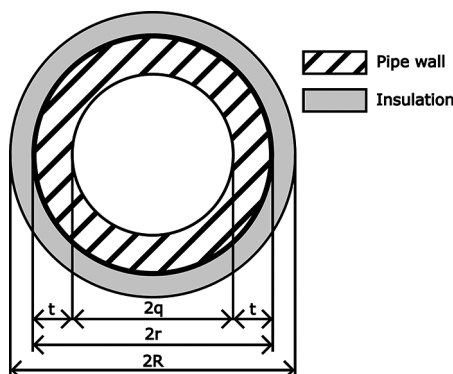


Fig. 5. Pipeline cross-section

tance directly depend on the geometry and material of the modeled pipe (Fig. 5).

The active resistance of the pipeline R_p is dependent on its cross-section

$$R_p = \rho \frac{l}{S},$$

where ρ is the resistivity of the pipeline material; l – the length of the section; S – the cross-sectional area equal to

$$S = \pi(r^2 - q^2),$$

where q is the inner radius of the pipeline; r – the outer radius of the pipeline.

The inductance of a pipeline is defined as the inductance of a hollow straight wire of circular cross-section

$$L_p = \frac{\mu_0 l}{2\pi} \left(\ln \frac{2l}{r} - 1 \right) + L_i,$$

where μ_0 is the magnetic constant; L_i – the internal inductance, which is equal to

$$L_i = \frac{\mu l}{2\pi m r} \frac{\sinh mt - \sin mt}{\cosh mt - \cos mt},$$

where μ is the magnetic permeability of the pipeline material; t – the pipe wall thickness;

$$m = \sqrt{2\omega\mu\gamma},$$

where $\omega = 2\pi f$ is the angular frequency; γ – the electrical conductivity of the material.

The capacitance of a pipeline can be roughly calculated by treating the pipeline segment as a cylindrical capacitor. In this case, the metal-insulation junction is the inner plate of the capacitor, and the insulation-ground junction is the second plate of the capacitor. As a result, the capacitance is equal to

$$C_{in} = \frac{2\pi\epsilon_0\epsilon l}{\ln \frac{R}{r}},$$

where ϵ_0 is the electric constant; ϵ – the dielectric constant of the insulation; R – the radius of the pipeline in the insulation.

The pipe-to-ground transient resistance is determined by the formula

$$R_{tr} = \frac{R_{tr, in}}{\pi D l},$$

where $R_{tr, in}$ is the transient resistance of the pipeline insulation depending on the resistivity of the soil, $\text{Ohm} \cdot \text{m}^2$; D – the diameter of the pipe in insulation.

The soil resistance is equal to

$$R_g = R_{tr} + R_a,$$

where R_a is the spreading resistance of the anode earth electrode, which is usually in the range of 1 to 4 Ohms.

The total resistance of the ground and insulation $R_g + R_{in}$ is equal to the value of the pipe-to-ground transient resistance R_{tr} .

Considering the equivalent circuit shown in Fig. 4 as a four-pole circuit, we can compose its transfer function.

For node 2', Kirchhoff's first law

$$\dot{I}_1 + \dot{I}_2 - \dot{I}_3 = 0. \quad (1)$$

Voltage drop according to Kirchoff's second law is

$$-\dot{U}_{in} + \dot{I}_1 \left(R_g + \frac{1}{sC_{in}} \right) + \dot{I}_3 (R_p + sL_p) = 0; \quad (2)$$

$$-\dot{U}_{in} + \dot{I}_2 R_r + \dot{I}_3 (R_p + sL_p) = 0. \quad (3)$$

Determine the currents \dot{I}_1 and \dot{I}_2 from equations (2) and (3)

$$\dot{I}_1 = \frac{\dot{U}_{in} - \dot{I}_3 (R_p + sL_p)}{R_g + \frac{1}{sC_{in}}};$$

$$\dot{I}_2 = \frac{\dot{U}_{in} - \dot{I}_3 (R_p + sL_p)}{R_r}.$$

Substitute the obtained currents into equation (1)

$$\frac{\dot{U}_{in} - \dot{I}_3 (R_p + sL_p)}{R_g + \frac{1}{sC_{in}}} + \frac{\dot{U}_{in} - \dot{I}_3 (R_p + sL_p)}{R_r} - \dot{I}_3 = 0.$$

Bring the fraction to a common denominator

$$(\dot{U}_{in} - \dot{I}_3 (R_p + sL_p)) \left(\frac{R_r + R_g + \frac{1}{sC_{in}}}{R_r \left(R_g + \frac{1}{sC_{in}} \right)} \right) - \dot{I}_3 = 0;$$

$$\frac{\dot{U}_{in} \left(R_r + R_g + \frac{1}{sC_{in}} \right)}{R_r \left(R_g + \frac{1}{sC_{in}} \right)} - \frac{\dot{I}_3 (R_p + sL_p) \left(R_r + R_g + \frac{1}{sC_{in}} \right)}{R_r \left(R_g + \frac{1}{sC_{in}} \right)} - \dot{I}_3 = 0.$$

Determine the current \dot{I}_3 from the equation

$$\frac{\dot{I}_3 (R_p + sL_p) \left(R_r + R_g + \frac{1}{sC_{in}} \right)}{R_r \left(R_g + \frac{1}{sC_{in}} \right)} + \dot{I}_3 = \frac{\dot{U}_{in} \left(R_r + R_g + \frac{1}{sC_{in}} \right)}{R_r \left(R_g + \frac{1}{sC_{in}} \right)};$$

$$\dot{I}_3 \left(\frac{\left(R_p + sL_p \right) \left(R_r + R_g + \frac{1}{sC_{in}} \right)}{R_r \left(R_g + \frac{1}{sC_{in}} \right)} + 1 \right) = \frac{\dot{U}_{in} \left(R_r + R_g + \frac{1}{sC_{in}} \right)}{R_r \left(R_g + \frac{1}{sC_{in}} \right)};$$

$$\dot{I}_3 \left(\frac{\left(R_p + sL_p \right) \left(R_r + R_g + \frac{1}{sC_{in}} \right) + R_r \left(R_g + \frac{1}{sC_{in}} \right)}{R_r \left(R_g + \frac{1}{sC_{in}} \right)} \right) = \frac{\dot{U}_{in} \left(R_r + R_g + \frac{1}{sC_{in}} \right)}{R_r \left(R_g + \frac{1}{sC_{in}} \right)};$$

$$\dot{I}_3 = \frac{\dot{U}_{in} \left(R_r + R_g + \frac{1}{sC_{in}} \right)}{\left(R_p + sL_p \right) \left(R_r + R_g + \frac{1}{sC_{in}} \right) + R_r \left(R_g + \frac{1}{sC_{in}} \right)}.$$

Taking into account that

$$\dot{I}_1 \left(R_g + \frac{1}{sC_{in}} \right) = \dot{U}_{out}.$$

Substitute \dot{I}_1 into equation (2)

$$-\dot{U}_{in} + \dot{U}_{out} + \frac{\dot{U}_{in} \left(R_r + R_g + \frac{1}{sC_{in}} \right) (R_p + sL_p)}{\left(R_p + sL_p \right) \left(R_r + R_g + \frac{1}{sC_{in}} \right) + R_r \left(R_g + \frac{1}{sC_{in}} \right)} = 0;$$

$$\dot{U}_{out} = \dot{U}_{in} \left(1 - \frac{\left(R_r + R_g + \frac{1}{sC_{in}} \right) (R_p + sL_p)}{\left(R_p + sL_p \right) \left(R_r + R_g + \frac{1}{sC_{in}} \right) + R_r \left(R_g + \frac{1}{sC_{in}} \right)} \right).$$

The transfer function is equal to the ratio

$$W = \frac{\dot{U}_{out}}{\dot{U}_{in}} = 1 - \frac{\left(R_{tr} + R_g + \frac{1}{sC_{in}}\right)(R_p + sL_p)}{(R_p + sL_p)\left(R_{tr} + R_g + \frac{1}{sC_{in}}\right) + R_{tr}\left(R_g + \frac{1}{sC_{in}}\right)}$$

Simplify the fraction

$$W = \frac{R_{tr}\left(R_g + \frac{1}{sC_{in}}\right)}{(R_p + sL_p)\left(R_{tr} + R_g + \frac{1}{sC_{in}}\right) + R_{tr}\left(R_g + \frac{1}{sC_{in}}\right)}$$

Expand the brackets and bring the transfer function to the canonical form

$$W = \frac{R_{tr}R_g + \frac{R_{tr}}{sC_{in}}}{R_pR_{tr} + R_pR_g + \frac{R_p}{sC_{in}} + sL_pR_{tr} + sL_pR_g + \frac{L_p}{C_{in}} + R_{tr}R_g + \frac{R_{tr}}{sC_{in}}}$$

Multiply the numerator and denominator by s

$$W = \frac{sR_{tr}R_g + \frac{R_{tr}}{C_{in}}}{sR_pR_{tr} + sR_pR_g + \frac{R_p}{C_{in}} + s^2L_pR_{tr} + s^2L_pR_g + s\frac{L_p}{C_{in}} + sR_{tr}R_g + \frac{R_{tr}}{C_{in}}}$$

$$W = \frac{sR_{tr}R_g + \frac{R_{tr}}{C_{in}}}{s^2(L_pR_{tr} + L_pR_g) + s\left(R_pR_{tr} + R_pR_g + \frac{L_p}{C_{in}} + R_{tr}R_g\right) + \frac{R_p}{C_{in}} + \frac{R_{tr}}{C_{in}}}$$

Rectifier circuit. All of the above points did not focus on the shape of the output signal of cathodic protection stations, and by default, it was assumed to be purely constant (Fig. 6, signal 1). However, this is often not entirely true, since a typical CPS is powered by a household single-phase AC voltage source, and it step-downs and rectifies it independently [17]. And this, in turn, affects the shape of the output signal (Figs. 7, 8), as a result, the real potential on the pipeline has a much more complex shape (Fig. 6, signals 2, 3).

This waveform contributes to part of the rectifier's output power at high frequencies (Fig. 9), and even mW at frequencies of 0.8 kHz can play a significant role. Because with increasing frequency [18, 19], the capacitor's AC resistance decreases, and therefore the equalization currents begin to partially flow through the insulation to ground and turn into drain-leakage currents. In other

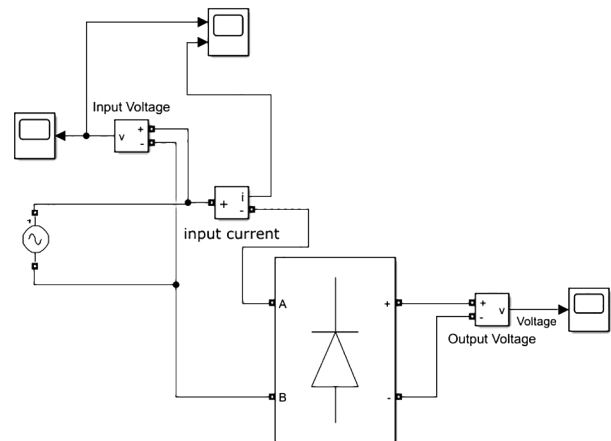


Fig. 7. Diode rectifier model

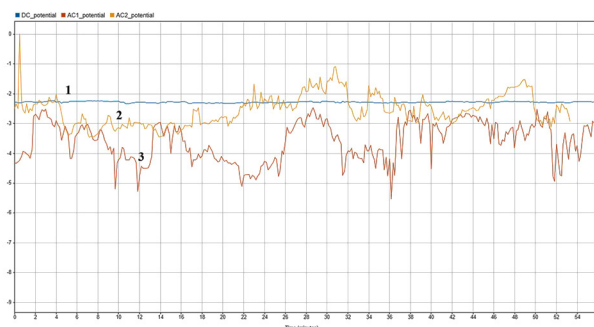


Fig. 6. Potential change over time at a point on different pipelines

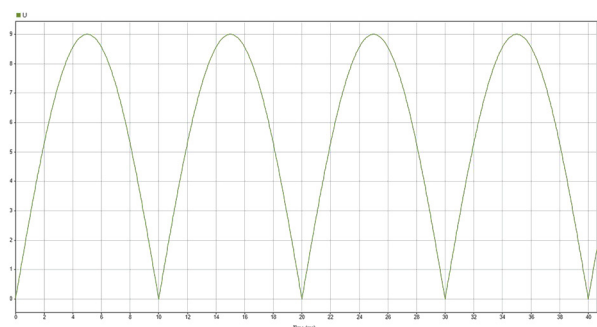


Fig. 8. Output signal of the diode rectifier

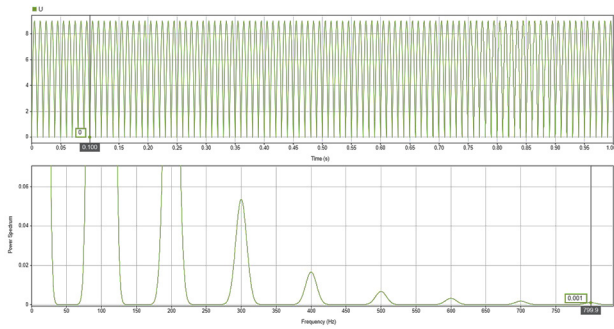


Fig. 9. Diode rectifier spectrum

words, as the power of high-frequency signals increases, so does the drain-leakage power.

Results of experimental monitoring of the protective potential. Measurements for pipelines of different diameters, laying depths, influencing factors, and heterogeneities (railroad tracks, urban electric transport, highways, etc.) are shown in Figs. 10–13. Figs. 10–14 show that the nature of the distribution of protective potentials indicates the possibility of its deviation from the classical perception compared to Fig. 1. Also, Figs. 10–13 shows a significant scattering of protection potential values along the pipeline, provided that they simultane-

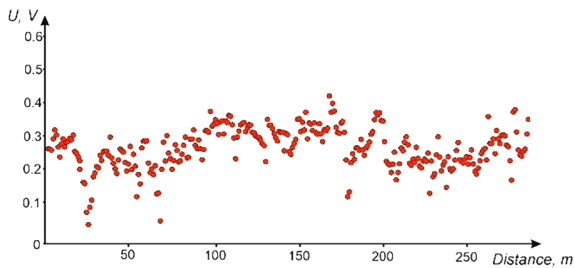


Fig. 10. Dependence of protective potential levels on distance in the presence of insulation damage

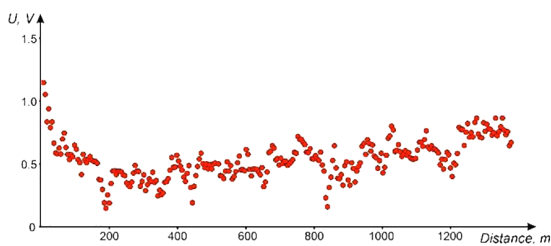


Fig. 11. Dependence of protective potential levels on distance in the presence of damage at a distance of 200, 420 and 825 m

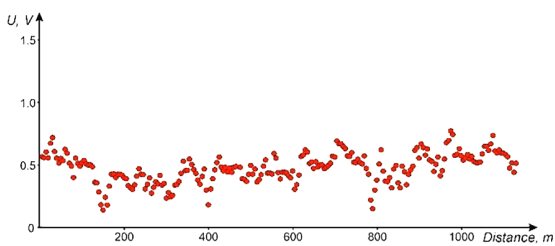


Fig. 12. Dependence of protective potential levels on distance in case of adjacent operation of CPSs

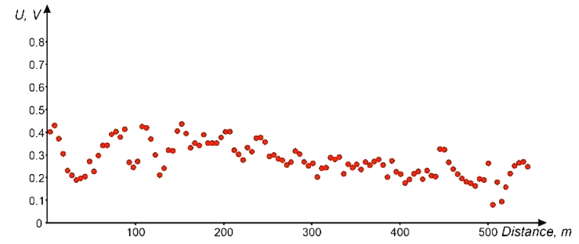


Fig. 13. Dependence of protective potential levels on distance in the presence of a variable component

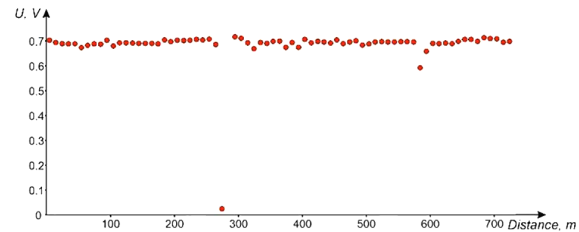


Fig. 14. Dependence of protective potential levels on distance in conditions of laying without stray currents

ously deviate from the standard distribution of Fig. 1. Under the condition that the underground steel pipeline has modern insulation and is protected by cathodic protection stations with high-frequency inverters, the change in the protective potential along the pipeline is insignificant (Fig. 14).

Conclusions. Energy-efficient and reliable operation of electrical systems for active cathodic protection of underground metal pipelines requires taking into account all factors of laying, soil characteristics and the presence of longitudinal polyethylene inserts used in maintenance. This is possible by obtaining analytical dependencies of the protective potential on the parameters of the protection system, taking into account point inhomogeneities.

The results of the experimental monitoring of the protective potential levels for various laying conditions and the number of adjacent CPSs allowed to identify the operating zones of permissible voltage levels. This substantiates the need to take into account the number and distance between polyethylene inserts for the rational distribution of stations along the entire pipeline distance.

Achieving the goal of creating reliable conditions for the protection of underground steel pipelines is possible by developing new dependencies for determining the potential levels under arbitrary combinations of heterogeneity factors and decision-making algorithms for adjusting system facilities. The adequacy of the obtained mathematical models is proved by various studies of the existing facilities of the Ukrainian GTS.

The above material indicates a significant corrosion hazard of equalization currents flowing over the pipeline surface, which in turn necessitates a more detailed consideration as a factor of negative impact.

The main feature that greatly complicates the consideration of the negative impact of equalization currents is the complexity of algorithms for their separation. Thus, it is quite reasonable to use algorithms for

the adaptive formation of protective potentials to the electrical parameters of the protected object.

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Вплив розподілу захисного потенціалу сталевго підземного трубопроводу на процеси електрохімічної корозії

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Мета. Виокремлення впливу вставок з високим опором протікання електричного струму, що обумовлює відхилення захисного потенціалу за довжиною трубопроводу від класичного. Отримання аналітичних залежностей у вигляді передатної функції, яка пов'язує вхідний і вихідний сигнал, що дозволяє прогнозувати небезпечні відхилення захисного потенціалу, комбінація значень якого свідчить про погіршення корозійного захисту.

Методика. Для досягнення поставленої мети використані методи теоретичного аналізу, математичного й комп'ютерного моделювання і спектрального аналізу сигналів. Вихідна інформація, що характеризує режими роботи суміжних станцій катодного захисту, була отримана й перевірена на основі даних моніторингу захисного потенціалу вздовж трас підземних сталевих трубопроводів різних конструкцій. Параметри, що враховані під час розрахунків: геометричні розміри трубопроводу, стан ґрунту, опір ізоляції тощо. Аналізуючи результати вимірювань, отриманих за допомогою реєструючого вольтметра «ПРИМА 2000» та трасошукача «Спрут-17», було встановлено й детально проаналізовано зростання корозійних ризиків, які виникають у результаті ремонту пошкодженої ділянки підземного сталевго трубопроводу з використанням поліетиленових труб.

Результати. Виконано моделювання режимів роботи суміжних станцій катодного захисту, між якими знаходиться ділянка поліетиленового трубопроводу, з електротехнічними параметрами підземного сталевго трубопроводу. На основі отриманої інформації звернута увага на можливі раціональні енергетичні режими роботи суміжних станцій катодного захисту, основним завданням яких є зниження корозійних впливів поліетиленового відрізка підземного трубопроводу.

Наукова новизна. Полягає в обґрунтуванні можливості такого негативного впливу поліетиленової вставки до сталевго трубопроводу, що підвищує захисному безпеку. Отримані залежності значень захисного потенціалу станцій катодного захисту на ділянках трубопроводу з поліетиленовими вставками від режимів роботи електротехнічної системи з перетворювачами енергії та їхніх алгоритмів фор-

мування напруги на виході станцій катодного захисту.

Практична значимість. Проведено аналіз сигналів випрямлячів станцій катодного захисту й режимів комутації силових ключів, що спрямовані на поліпшення складної корозійної ситуації на трубопроводах низького й середнього тисків, для яких є характерною неоднорідність структури, особливо в межах населених пунктів. Запропоновані режими роботи суміжних станцій катодного

захисту знижують рівень корозійної небезпеки, викликаний масовим упровадженням поліетиленових труб і їх широким використанням для ремонту пошкоджених ділянок сталевих трубопроводів.

Ключові слова: підземний сталевий трубопровід, катодний захист, електрохімічна корозія, електротехнічні параметри трубопроводу

The manuscript was submitted 12.02.25.