УДК 621.311 **doi: 10.20998/2313-8890.2026.03.05**

Omelchuk Anatoli, candidate technical of Science, associate professor, +3(050)627-45-52, omelchuk_anatoli@ukr.net, ORCID ID: 0009-0007-3964-497X
National Technical University of Ukraine «Ihor Sikorsky Kyiv Polytechnic Institute»
37 Beresteyskyi Avenue, Kyiv, 03056

RESEARCH ON THE OPERATION OF REMOTE PROTECTION OF DISTRIBUTION NETWORKS WITH GENERATION SOURCES

Abstract. *The article investigates the parameters of remote protection with a time delay dependent on the short-circuit loop resistance for distribution lines with sectioning, redundancy and distributed generation sources (DGS) in the event of asymmetrical short circuits, taking into account the features of the parameters and operating modes of these networks. The characteristics of protection devices recommended for setting up remote protection of such lines with a voltage of 6…20 kV are obtained. The advantages of using a remote protection connection scheme for phase-to-phase voltages and phase current differences, as well as the use of separate protection against double ground faults, and in their absence – connection schemes for line voltages and phase currents, are substantiated.*
The selectivity and sensitivity of the operation of full-resistance remote protection must be assessed by the value of the maximum arc length, which is determined at a given sensitivity coefficient of remote protection by the voltage drop at the point of installation of protection in the event of an asymmetrical short circuit.
Keywords: *distribution networks, distance protection, asymmetrical short circuit, distributed generation sources, sensitivity, selectivity.*

Омельчук Анатолій Олександрович, канд. техн. наук, доцент кафедри автоматизації енергосистем, +38(050)627-45-52, omelchuk_anatoli@ukr.net, ORCID ID: 0009-0007-3964-497X
Національний технічний університет України «Київський політехнічний інститут імені Ігоря Сікорського»
Берестейський проспект, 37, м. Київ, 03056

ДОСЛІДЖЕННЯ РОБОТИ ДИСТАНЦІЙНОГО ЗАХИСТУ РОЗПОДІЛЬНИХ МЕРЕЖ З ДЖЕРЕЛАМИ ГЕНЕРАЦІЇ

Анотація. *У статті досліджені параметри дистанційних захистів з залежною від опору петлі короткого замикання витримкою часу для розподільних ліній з секціонуванням, резервуванням та джерелами розподіленої генерації (ДРГ) при несиметричних коротких замиканнях з урахуванням особливостей параметрів і режимів роботи цих мереж. Отримані характеристики пристроїв захисту, котрі рекомендуються при налагодженні дистанційного захисту таких ліній напругою 6…20 кВ. Обґрунтовано переваги використання схеми приєднання дистанційного захисту на міжфазні напруги і різницю фазних струмів, а також використання окремого захисту від подвійних замикань на землю, а при їх відсутності - схеми приєднання на лінійні напруги і фазні струми.*
Селективність і чутливість роботи дистанційного захисту повного опору необхідно оцінювати за величиною максимальної довжини дуги, котра визначається при заданому коефіцієнті чутливості дистанційного захисту зниженням напруги в місці встановлення захисту при несиметричному короткому замиканні.
Ключові слова: *розподільні мережі, дистанційний захист, несиметричне коротке замикання,*

джерела розподіленої генерації, чутливість, селективність.

Introduction. Since the current distribution electric networks are mainly radial-type networks and the power flow is unidirectional from the main section to the final consumers, the existing current protection with the function of automatic reactivation on the main feeder of the feeding substations is not designed for the existence of additional sources of distributed generation, which create a number of problems for the relay protection [1].

In particular, this problem is related to the use of automatic reconnection devices, which are quite common in distribution networks, together with sources of distributed generation. A power-free pause during the operation of automatic reconnection, as a rule, lasts a fraction of a second, which does not cause great damage to consumers. In the event that the protection of distributed generation sources fails during the de-energized restart pause, such source remains connected to the networks and will maintain the network voltage, and therefore the arc will not be attenuated and the damage will not self-repair, resulting in a significant interruption in electricity supply.

But if even the source of distributed generation will be disconnected during the current-free pause of reconnection, then the time allocated for elimination of the arc is reduced by the time of protection of the sources of distributed generation. To avoid the appearance of these and other undesirable situations during the operation of electric networks, the task of coordinating the operation of re-starting with the operation of protection of sources of distributed generation must be solved.

The next problem is related to the complication of relay protection systems of networks with sources of distributed generation, for example, when short circuits occur outside the feeder with a source of distributed generation, but within the same substation, this source feeds the short circuit. In this situation, the protection at the beginning of the line with this source can operate, which is possible when the direction of current flow is not taken into account. Therefore, the use of remote protection in such networks allows solving this problem.

The next problem of non-selective operation of the protection may arise in the network when the source of distributed generation is located between the short-circuit point and the busbars of the power substation: this source participates in the short-circuit supply, thereby increasing the current.

It should also be noted that the connection of sources of distributed generation can lead to a delay in the operation of the relay protection of the power feeder - this is determined by the time of protection of the sources of distributed generation themselves. At the current stage, this is implemented by microprocessor systems for protection and management of such networks with sources of distributed generation [2].

According to the results of studies [3–4] of the conditions of coordination of adjacent remote protections taking into account the parameters and modes of operation of power transmission lines with sources of distributed generation, the sensitivity and selectivity of remote protection in case of various types of short circuits is relevant.

In [4], the results of the study of the modes of power transmission lines, in particular, the load currents of these lines and the transient resistance at the short circuit during three-phase short circuits and their influence on the parameters and schemes of remote protection in such lines with a voltage of 10 kV with sources of distributed generation are given.

The setting of remote protections is complicated by the fact that in order to ensure unambiguous measurement of the short-circuit loop in case of interphase damage and in case of double earth faults in networks with an isolated neutral in the current and voltage circuits that feed the protection, switching is performed from the measurement of linear currents (I_L) and voltage (U_L) on phase currents and voltages with the use of zero-sequence current compensation I0 in the circuits where $I_0 \neq 0$.

Purpose and tasks.

Changes in the parameters and modes of operation of distribution networks caused by sources of distributed generation require the determination of their influence on the performance of relay protection devices of such networks, in particular, power transmission lines – in works [3–4] the results of research in the case of symmetrical short circuits are highlighted.

In the case of phase-to-phase short-circuits, the measurement of the resistance of the short-circuit loop is ensured by applying to the reacting body of the remote relay a voltage proportional to the voltage between the damaged phases U_L and the difference in the currents of the damaged phases – I_L. In this case, the resistance at the input terminals of the relay for two-phase $Ƶ^{(2)}$ and three-phase $Ƶ^{(3)}$ short circuits is proportional to the resistance of the direct sequence of the line to the short circuit:

$$Ƶ^{(2)} = Ƶ^{(3)} \approx \frac{U_L}{I_L} \approx Ƶ_1 l, \qquad (1)$$

where $Ƶ_1$ is the specific resistance of the direct sequence of the power transmission line, Ohm/km; l – length of the power transmission line to the point of shorting, km.

Unfortunately, the indicated method of connection does not provide similar measurements in the mode of double phase-to-ground shorting – with such shorting on one line by the protection device I (Fig. 1), at the place of installation of which $I_0=0$, resistance proportional to the distance to the most distant point of shorting is measured. This is explained by the expression of the voltage (2) between the damaged phases (U_{BC}) and the current difference (3) of the damaged phases (I_{BC}):

$$U_{BC}=U_B - U_C = I_B \cdot Ƶ_1 \cdot l_2 + I_B \cdot X_L \cdot (l_1 + l) - I_C \cdot Ƶ_1 \cdot l_2 \approx 2 \cdot Ƶ_1 \cdot I_B \cdot (l_2 + l_1 + l), \qquad (2)$$

where X_L is the specific inductive resistance of the «phase-ground» loop (for lines without lightning protection cables $X_L = 1,83 \cdot Ƶ_1$).

$$I_{BC} = I_B - I_C = 2I_B, \qquad (3)$$

$$Z_{Z1} = \frac{U_{BC}}{I_{BC}} = Z_1 \cdot (l_2 + l_1 + l). \qquad (4)$$

The voltage supplied to the protection device 2 installed at the redundancy point (where $I_0 \neq 0$) is determined by the expression:

$$U_{BC} = I_B \cdot Ƶ_l \cdot l + I_B \cdot X_M \cdot l_1 = 1,83 \cdot I_B \cdot Ƶ_1 \cdot (l + 0,45 \cdot l_1), \qquad (5)$$

where X_M is the specific resistance of mutual induction between phases (for lines without lightning protection cables $X_M = 0,83 \cdot Ƶ_1$).

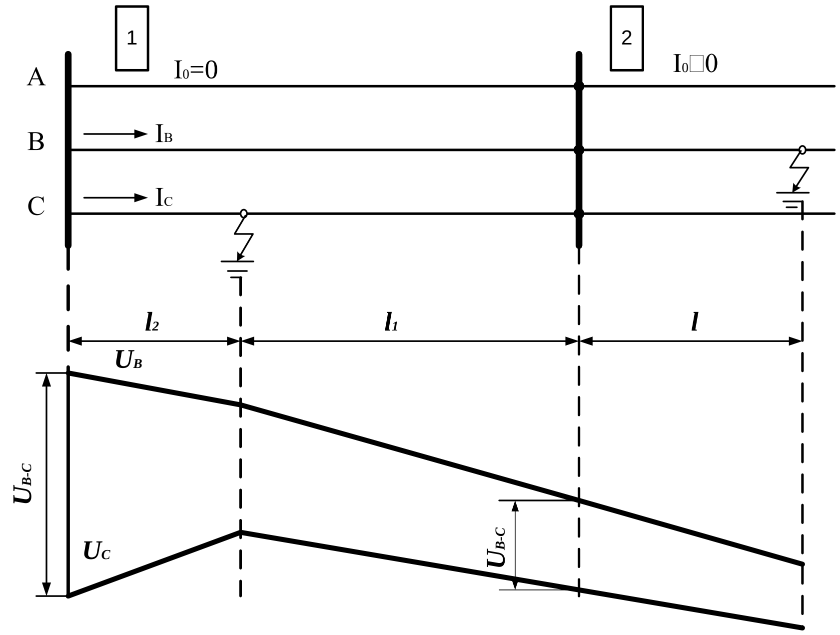

Figure 1 – Change in voltage along the power line during a double earth fault (1, 2 – line protection kits).

The resistance at the input of protection device 2 Z_{Z2} is determined according to the expression:

$$Z_{Z2} = \frac{U_{BC}}{I_{BC}} = 1{,}83 \cdot Z_1 \cdot (l + 0{,}45 \cdot l_1). \tag{6}$$

Expressions (4) and (6) indicate that selective protection work is possible under the condition $(l_2 + 0{,}17 \cdot l_1) > 0{,}83 \cdot l$.

In the case of double grounding on different outgoing lines of the same substation (Fig. 2), the resistance at the input of protection devices 1 and 2 is determined by expression (7):

$$Z_{Z1} = Z_{Z2} = \frac{U_{BC}}{I_{BC}} = 1{,}83 \cdot Z_1 \cdot (l_1 + l_2). \tag{7}$$

The supports that are fixed by the protection device during such a circuit correspond to the total distance to the circuit points on both lines, increased by 1.83 times.

Therefore, when remote protection monitors line voltages and the difference in currents of damaged phases, protection devices installed in places where, in case of double earth faults, $I_0 \neq 0$, measure a resistance greater than the resistance of the short-circuit loop in the protected area, and often greater than the tripping resistance this protection device.

In such cases, to ensure reliable resistance measurement, switching is performed in the current and voltage circuits of the protection device, which ensure the connection of the device to the phase voltage U_F and to the phase current compensated by the zero-sequence current ($I_F + k \cdot I_0$).

Such switching is possible if there are three current transformers and three single-phase (or one three-phase) voltage transformers on the outgoing lines.

Therefore, the use of such methods of connecting devices for remote protection of lines with redundancy and sources of distributed generation would lead to a significant complication of the protection itself and the primary schemes of redundancy points and cells for connecting sources of distributed generation, due to the need to install additional current and voltage transformers.

Research materials and methods**.**

We will conduct a study of resistance measurement in all types of circuits when using the protection scheme:

- with the connection of the protection device to voltages proportional to the voltage between the damaged phases U_L and the current of the damaged phase I_F in the modes (when there is no zero-sequence current at the place of installation of the protection device I_0=0);

- and with voltage switching from linear to phase U_F in the presence of a zero-sequence current at the location of the protection installation.

The conducted research is aimed at obtaining a simpler method of resistance measurement for all types of circuits in the studied power lines.

In the three-phase short-circuit mode, the measured resistance corresponds to the expression:

$$Z^{(3)} = \frac{U_L}{I_L} = 1{,}73 \cdot Z_1 \cdot l. \quad (8)$$

In the two-phase short-circuit mode – by expression (9)

$$Z^{(2)} = \frac{U_L}{I_L} = 2 \cdot Z_1 \cdot l. \quad (9)$$

In the mode of a double short circuit to the ground on one line (Fig. 1), the resistance is measured by the protection device 1:

$$Z_{Z1} = 1{,}83 \cdot Z_l \cdot (l_2 + l_1 + l), \quad (10)$$

and protection device 2 when connected to the voltage of phase B – the resistance is measured:

$$Z_{z1}^{(1,1)} = \frac{U_B}{I_B} = \frac{I_B \cdot Z_1 \cdot l}{I_B} = 1{,}83 \cdot Z_1 \cdot l, \quad (11)$$

Since $Z_{Z1} > Z_{Z2}$, selective operation of protection devices 1 and 2 is always ensured.

In the case of a double short-circuit to the ground on different outgoing lines of the same substation (Fig. 1), both protection devices 1 and 2 are connected to a voltage proportional to the current and the voltage of the damaged phase, since current I0 flows in the place of installation of both protection devices. At the same time, each of the devices measures the resistance proportional to the resistance of the direct sequence of the line to the shorting point:

$$Z_{Z1} = 1{,}83 \cdot Z_l \cdot l_1,$$

$$Z_{Z2} = 1{,}83 \cdot Z_l \cdot l_2. \quad (12)$$

In this case, the line with the closing point closest to the substation is disconnected first.

The ratio of resistance measurements for different types of circuits is as follows:

$$Z^{(3)} : Z^{(2)} : Z^{(1,1)} = 1{,}73 : 2 : 1{,}83.$$

The application of such a protection scheme also requires control and measurement of the phase voltage of the line.

Therefore, in 10 kV lines with sources of distributed generation, it is advisable to use remote protection that uniquely reacts to interphase short circuits at one point and is performed according to the scheme of connecting to voltages and currents between damaged phases U_L and I_L, and to protect against double circuits to the ground, use separate devices responding to zero sequence current.

This implementation of remote protection devices is also advisable because even common maximum current protections of radial lines do not always provide the necessary sensitivity in case of double earth faults. For example, in the event of a double earth fault on different outgoing lines of the same substation, due to the high resistance of the short-circuit loop, the sensitivity of the current protections turns out to be insufficient.

If the distances to the short circuit locations are equal ($l_2 = l_1$), the sensitivity of the protection during a double short circuit to the ground decreases by 1.84 times.

In the absence of ground fault protection on power transmission lines, it would be advisable to connect remote protection to voltages proportional to the current of the damaged phase I_F and the voltage between the damaged phases U_L. In this case, in the event of a double short circuit to the ground and the presence of I_0 at the place of its installation, it is necessary to «roughen» the protection to a lesser extent than when connecting to line currents and the difference in the currents of the damaged phases.

When connecting the protection device to voltages proportional to the current of the damaged phase I_F and the voltage between the damaged phases U_L, the resistance is measured:

- with a three-phase short circuit $Z_Z^{(3)} = 1{,}73 \cdot Z_1 \cdot l$).

- with a two-phase short circuit $Z_Z^{(2)} = 2 \cdot Z_1 \cdot l$).

In the case of double grounding at different points of the same power line, the resistance at the input of protection device 1 corresponds:

$$Z_{Z1} = \frac{U_{BC}}{I_B} = 2 \cdot Z_1 (l + l_1 + l_2). \qquad (13)$$

and at the input of protection device 2

$$Z_{Z2} = \frac{U_{BC}}{I_B} = 1{,}83 \cdot Z_1 (l + 0{,}45 \cdot l_1). \qquad (14)$$

Since $Ƶ_{Z2} > Ƶ_{Z1}$, selective protection action is always provided.

In the mode of two-phase short circuit protection, which is connected to the line voltage and the difference in the currents of the damaged phases, the resistance is measured (Fig. 2):

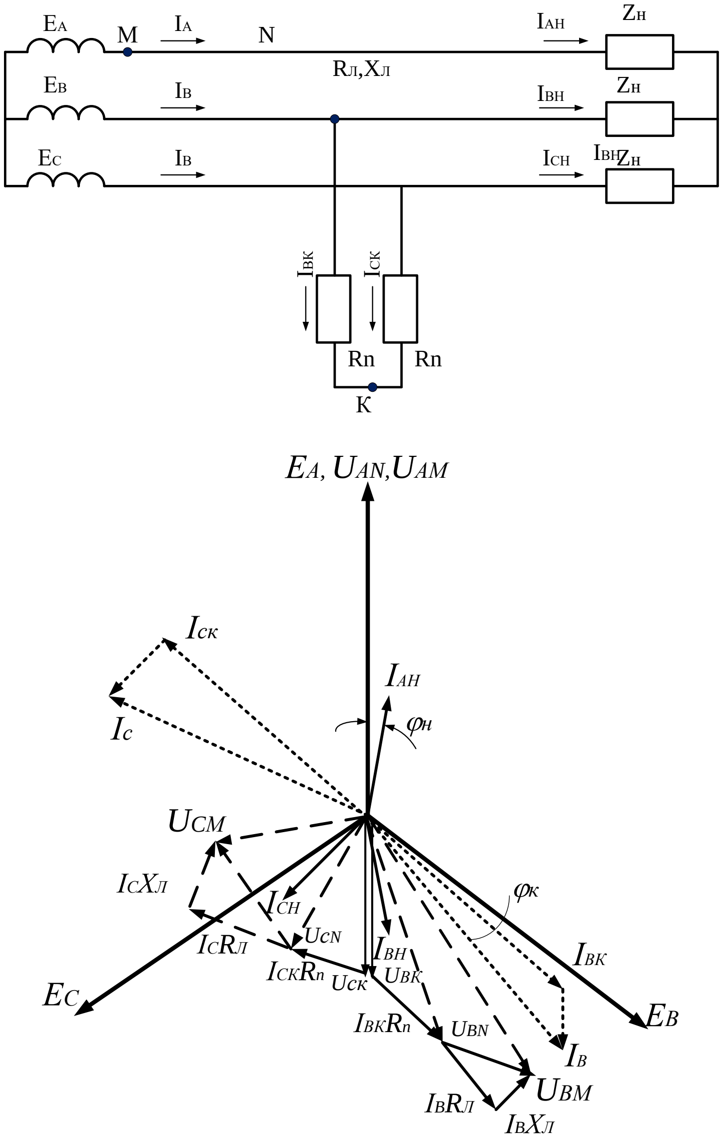

Figure 2 – Vector diagram of currents and voltages during a two-phase short circuit due to the transient resistance Rn, taking into account the load currents.

$$Z_{z1}^{(2)} = \frac{(I_B - I_C)Z_л + I_{Bk}2}{(I_B - I_C)} R_p = Z_L + 2R_n \frac{I_{Bk}}{I_B - I_C}, \qquad (15)$$

or

$$Z_{z1}^{(2)} = Z_L + 2R_n \frac{I_{Bk}}{2I_{Bk} + (I_{B\text{Н}} - I_{\text{СН}})}, \qquad (16)$$

When $R_п = 0$ $\quad Z_{z1}^{(2)} = Z_л$

When $I_{BН} = I_{СН} = 0$

$$Z_{z1}^{(2)} = Z_L + R_n. \tag{17}$$

Taking into account the difference in currents in expression (15)

$$\dot{I}_B - \dot{I}_C = \frac{\dot{U}_L - \dot{I}_{Bk} \cdot 2 \cdot R_n}{Z_L}, \tag{18}$$

and the value of R_n in accordance with (20) [4], we get an expression for determining the resistance of the remote relay:

$$Z_{z1}^{(2)} = Z_L \cdot \frac{\dot{U}_L}{\dot{U}_L - 1050 \cdot 2 \cdot l_d}, \tag{19}$$

The ratio of the measured resistance to the resistance of the remote relay setting is:

$$\frac{Z_{z1}^{(2)}}{Z_{уст}} = \frac{1}{К_{ch} \cdot \left(1 - \frac{1050 \cdot 2 \cdot l_d}{\dot{U}_L}\right)}, \tag{20}$$

From here, the length of the electric arc, at which the resistance at the relay terminals does not exceed the resistance of the setting of this relay, will be equal to

$$l_d \leq \frac{(К_{ch} - 1) \cdot \dot{U}_L}{1050 \cdot 2 \cdot К_{ch}}. \tag{21}$$

At K_{ch}=1.5 for lines with a voltage of 10 kV

$$l_d \leq 1{,}67 \cdot K_u. \tag{22}$$

where $K_u \leq \frac{U_Ф}{U_{ФН}}$ – the ratio of the phase voltage at the installation location of the short-circuit protection device to the nominal voltage.

The error introduced by the transient resistance of the arc during a two-phase short circuit for lines with a voltage of 10 kV is determined by the expression

$$\delta_{d1}^{(2)} = \frac{2 \cdot l_d}{10 \cdot K_u - 2 \cdot l_d}, \% \tag{23}$$

The coefficient of protection sensitivity, at which its sensitivity is ensured at the maximum possible length of the arc in the line with a voltage of 10 kV

$$К_{ch1}^{(2)} \geq \frac{K_u}{K_u - 0{,}2 \cdot l_{d.max}}, \tag{24}$$

We will analyze the influence of transient resistance at the point of damage and load currents on the operation of remote protection, which is connected according to the second scheme [3, 4] – on the line voltage and current of the damaged phase.

With a three-phase short circuit, the resistance at the relay terminals is determined by the ratio

$$Z_{z2}^{(3)} = \frac{\dot{U}_L}{\dot{I}_F} = \frac{(\dot{I}_B - \dot{I}_С) \cdot Z_L + (\dot{I}_{Bk} - \dot{I}_{Сk}) \cdot R_n}{\dot{I}_B}, \tag{25}$$

Taking into account the currents I_B, I_C according to (18) [4], after transformation we obtain

$$Z_{z2}^{(3)} = \frac{Z_L \cdot [\sqrt{3} \cdot \dot{I}_k + (\dot{I}_{BН} - \dot{I}_{СН})] + \sqrt{3} \cdot \dot{I}_k \cdot R_n}{\dot{I}_k + \dot{I}_Н}, \tag{26}$$

With a symmetrical load of the electrical network, which is more typical for networks with a voltage of 10 kV, the last expression will have the form

$$Z_{z2}^{(3)} = \sqrt{3} \cdot (Z_L + R_n \frac{\dot{I}_k}{\dot{I}_k + \dot{I}_Н}), \tag{27}$$

Taking into account (I_k+$I_Н$) according to expression (20) [4] and Rn according to (21) [4], after transformations we obtain

$$Z_{z2}^{(3)} = \sqrt{3} \cdot Z_L \frac{\dot{U}_F}{\dot{U}_F - 1050 \cdot \dot{l}_d}, \tag{27}$$

The ratio of the measured resistance and the resistance of the remote protection setting at Z_{ust}=1,73·$Z_л$·$К_{ch}$

$$\frac{Z_{z2}^{(3)}}{Z_{ust}} = \frac{1}{К_{ch}} \cdot \left(\frac{1}{1 - \frac{1050 \cdot l_d}{\dot{U}_F}} \right). \tag{28}$$

The error introduced by the transient resistance of the arc during a three-phase short circuit for lines with a voltage of 10 kV is determined by the expression

$$\delta_{d1}^{(3)} = \frac{l_d}{\frac{10}{\sqrt{3}} \cdot K_u - l_d}, \% \tag{29}$$

The coefficient of protection sensitivity, at which its sensitivity is ensured at the maximum possible length of the arc in the line with a voltage of 10 kV

$$К_{ch2}^{(3)} \geq \frac{K_u}{K_u - \frac{10}{\sqrt{3}} \cdot l_{d.max}}, \tag{30}$$

Similarly, the given ratio of resistances for a two-phase short circuit between phases B and C is determined, which, taking into account the currents I_B and I_C from expression (18) [4]

$$Z_{z2}^{(2)} = 2Z_L \cdot \left[1 - \frac{\dot{I}_{BН} - \dot{I}_{СН}}{2 \cdot (\dot{I}_{Bk} + \dot{I}_{BН})}\right] + 2R_n \frac{\dot{I}_{Bk}}{\dot{I}_{Bk} + \dot{I}_{BН}}, \tag{31}$$

From expression (18), the current value of the damaged phase can be determined as

$$\dot{I}_B = \frac{1}{2}\left[\frac{\dot{U}_L - \dot{I}_{Bk} \cdot 2 \cdot R_n}{Z_L} + \dot{I}_{BН} + \dot{I}_{СН}\right], \tag{32}$$

Resistance at the terminals of the remote relay taking into account (32)

$$Z_{z2}^{(2)} = \frac{2 \cdot \dot{U}_L}{\frac{\dot{U}_L - 1050 \cdot 2\dot{l}_d}{Z_L} + (\dot{I}_{BН} + \dot{I}_{СН})}, \tag{33}$$

The minimum value of the sensitivity coefficient of the remote protection enabled according to the second scheme (on the line voltage and current of the damaged phase), at which Zmeas<Zust at the maximum length of the electric arc is determined by the ratio

$$К_{ч2}^{(2)} \geq \frac{\dot{U}_L}{\dot{U}_L - 1050 \cdot 2\dot{l}_{d.max} + Z_L \cdot (\dot{I}_{BН} + \dot{I}_{СН})}, \tag{34}$$

Conclusions. The scientific value of the research is the obtained analytical dependences for evaluating the reliability of measuring the resistance of the damaged section of the line by remote protection devices when connecting it according to both schemes, namely, the measurement error and the minimum value of the sensitivity coefficient and the maximum arc length, when $Z_{meas} < Z_{ust}$.

When Ku changes in the range of 0.6...0.9, the maximum length of the electric arc at which protection is triggered exceeds 1 m, which happens most often and is dangerous for 10 kV lines on reinforced concrete supports. This confirms the expediency of using in branched, redundant lines and in lines with RDG networks of remote protection of full resistance.

The obtained research results showed the following:

- errors of resistance measurement by remote protection devices for remote short-circuits at ld=1 m and Ku=0.6...0.9 are within 24...41 % at three-phase short-circuit for both schemes under consideration;

- in case of remote symmetrical short-circuits, due to transient resistance and Kch=1.5, remote protection is triggered.

With a two-phase short circuit and connecting the remote relay to the line voltage and phase current, the load currents affect the measured resistance of the remote relay in a decreasing direction, even with a “metal” short circuit. In case of a short circuit due to a transient resistance, the load currents have less influence on the resistance measured by the remote relay.

The practical value of the work is the analysis of the parameters and modes of operation of such lines and the determination of the protection characteristics, in particular:

- limits for adjusting the trigger resistance – (0.1...8) Ohm;
- limits of adjustment of the activation time at the end of the protection zone – 1...6 s;
- accurate triggering current – 4 A at a setting of 0.4 Ohm/phase;
- requirements for the linearity of time characteristics and the uncertainty limit of protection characteristics.

The obtained results are recommended to be used when setting up remote protection of 6...20 kV lines with sources of distributed generation and backup power.

The analysis of the operation of remote protection with different types of circuits showed that in electrical networks with sources of distributed generation, it is advisable to use remote protection schemes with control of line voltages and the difference in phase currents. To protect such lines from double short circuits to the ground, use a separate protection, and if it is not available – connect the main protection to line voltages and phase currents.

It is advisable to evaluate the effectiveness of the remote protection of full resistance by the maximum length of the electric arc, which is determined by the voltage drop at the place of installation of the protection with the corresponding coefficient of sensitivity of the protection.

In the power transmission lines under consideration, the maximum length of the arc at which protection is triggered in the case of remote short-circuits exceeds 1 m, which confirms the effectiveness of remote full-resistance protections

БІБЛІОГРАФІЧНИЙ СПИСОК:

1. Kirylenko O. V., Pavlovsky V. V., Lukyanenko L. M. Technical aspects of implementation of sources of distributed generation in electric networks // *Technical electrodynamics*, 2011. № 1. P. 46–53.
2. Grebchenko M.V. Fast-acting adaptive protection against short circuits in microgrid electrical networks with distributed generation// Grebchenko M. V., Yeryomenko E. V. *Technical electrodynamics*, 2021. № 1.
3. Simulation of criteria for selection of remote protection settings with remote starting in lines with distributed sources. Semen Voloshyn, Anatolii Omelchuk, Oleh Tarasiuk, Liudmyla Titova and Yuriy Gumenyuk. Publication: IOP Conference Series: Materials Science and Engineering. Volume 1030, Issue 1. P. 012179 (2021). Pub Date: January 2021 DOI: 10.1088/1757-899X/1030/1/012179 Bibcode: 2021MS&E.1030a2179V.
4. Omelchuk A. O. Protection of power transmission lines with sources of distributed generation / S.P. Denisyuk, A.O. Omelchuk, D.G. Derevyanko //*Energy saving. Energy. Energy audit*, 2023. №. 1–2 (179–180). p. 15–27. http://eee.khpi.edu.ua/article/view/278762.

REFERENCES:

1. Kirylenko O. V., Pavlovsky V. V., Lukyanenko L. M. Technical aspects of implementation of sources of distributed generation in electric networks // *Technical electrodynamics*, 2011. № 1. P. 46–53.
2. Grebchenko M.V. Fast-acting adaptive protection against short circuits in microgrid electrical networks with distributed generation// Grebchenko M. V., Yeryomenko E. V. *Technical electrodynamics*, 2021. № 1.

3. Simulation of criteria for selection of remote protection settings with remote starting in lines with distributed sources. Semen Voloshyn, Anatolii Omelchuk, Oleh Tarasiuk, Liudmyla Titova and Yuriy Gumenyuk. Publication: IOP Conference Series: Materials Science and Engineering. Volume 1030, Issue 1. P. 012179 (2021). Pub Date: January 2021 DOI: 10.1088/1757-899X/1030/1/012179 Bibcode: 2021MS&E.1030a2179V.

4. Omelchuk A. O. Protection of power transmission lines with sources of distributed generation / S.P. Denisyuk, A.O. Omelchuk, D.G. Derevyanko //*Energy saving. Energy. Energy audit*, 2023. №. 1–2 (179–180). p. 15–27. http://eee.khpi.edu.ua/article/view/278762.

Стаття надійшла до редакції:14.02.2026; рецензування: 25.02.2026;
прийнята до публікації 05.03.2026. Автори прочитали и дали згоду рукопису.
The article was submitted on 14.02.2026; revised on 25.02.2026; and accepted for publication on 05.03.2026. The authors read and approved the final version of the manuscript.