1. Aleksandr KULIKOV[1], 2. Pavel PELEVIN[1], 3. Anton LOSKUTOV[1], 4.Evgeny KRYUKOV[1], 5.Alexey LOSKUTOV[1]

Department of Electric Power Engineering, Power Supply and Power Electronics, Nizhny Novgorod State Technical University n.a. R.E. Alekseev, Nizhny Novgorod, Russia (1)

ORCID: 1. 000-0003-1092-7136; 2. 0000-0002-6292-8168; 3. 0000-0003-2228-596X; 4. 0000-0002-9145-2453; 5. 0000-0003-1961-1728

doi:10.15199/48.2022.07.08

Methods for the implementation of automatic reclosing on combined overhead and underground cable power lines 110-500 kV

***Abstract**. The article discusses the existing and prospective methods of automatic reclosing of cable-overhead power lines. An overview description is given. The analysis of the features of the considered methods is carried out, the advantages and disadvantages are reflected, the structural diagrams are presented, the areas of application are determined. Highlighted the prospects of methods of automatic reclosing on combined overhead and underground cable power lines on the basis of wave principles.*

***Streszczenie.** W artykule omówiono istniejące i przyszłe metody automatycznego ponownego załączania kablowych linii napowietrznych. Podano opis ogólny. Przeprowadzana jest analiza cech rozważanych metod, uwzględniono zalety i wady, przedstawiono schematy strukturalne, określono obszary zastosowań. Zwrócono uwagę na perspektywy metod automatycznego SPZ na liniach napowietrznych w oparciu o zasady falowe. (**Metody realizacji automatycznego SPZ wł. połączone napowietrzne i podziemne linie elektroenergetyczne 110-500 kV**)*

Keywords: automatic reclosing (AR), combined overhead and cable power lines (OCPLs), fault location (FL), traveling wave patterns,.
Słowa kluczowe: automatyczne SPZ, kombinowane linie napowietrzne i kablowe, lokalizacja zwarcia, przebiegi fali biegnącej.

Introduction

In Russia, in accordance with the Electrical Installation Rules [1], clause 3.3.2. “... Automatic reclosing of overhead and mixed (cable-overhead) lines of all types of voltages above 1 kV should be provided. Refusal to use automatic reclosing should be justified in each individual case. "

However, in electrical practice, there are no conventional technical solutions that provide automatic reclosing (AR) of combined overhead and underground cable power lines (OCPLs) of high voltage (for example, 110 kV and above).

To ensure economic efficiency, high-voltage OCPLs are used in the area of megalopolises. At the same time, from the point of view of safety and prevention of injury to people, it is advisable to implement AR of OCPLs in case of fault in overhead sections and block automatic reclosing in case of fault in cable sections. Indeed, re-energizing a faulted high-voltage cable placed in the area of residential buildings can lead to significant damage, injury, and even death. At the same time, overhead to cable transitions, performed, as a rule, directly on transmission line towers, pose a particular danger. It should be noted that faults on high-voltage cables, as a rule, are permanent faults, and cable must be tested before re-energizing.

Therefore, for effective AR of high-voltage OCPLs, it is necessary to determine with high accuracy on which of the sections (overhead or cable) the fault occurred. And when eliminating fault on the overhead section, implement AR of power lines.

Until the 2000s, high-voltage cables with XLPE insulation were not massively used in Russia. The technology of production and installation of these cables has not been debugged until recently. Therefore, faults were caused generally by cable insulation breakdown itself. Now the problem of faults on cable lines (CL) is mainly associated with the movement of the ground due to large dynamic forces to the surface, the presence of a large amount of communication infrastructure in big cities, the work of construction equipment in the area of cable route. Also, the faults location have shifted closer to the overhead-to-cable transition, to the place of installation of the cable sleeve, which tends to be faulted as a result of exposure to aggressive weather conditions (for example, thawing-and-freezing cycles).

Therefore, the problem of selective AR of OCPLs is especially relevant in case of faults close to the transition points, which requires the development of more accurate methods and algorithms.

Existing technical solutions in Russia and Europe

At present, there are several existing technical solutions for AR of OCPLs.

In the JSC "United Energy Company" at the 220 kV Substation "Gertsevo", the project of AR of OCPLs based on optical current transformers (CT) was implemented [2].

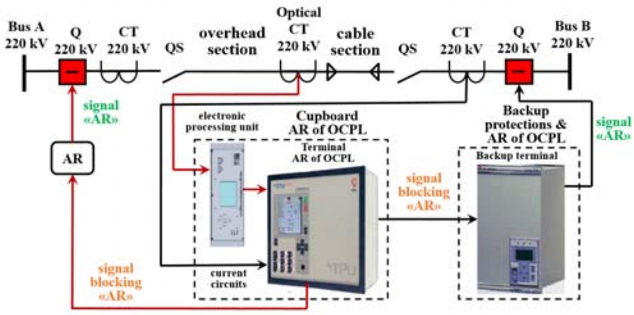

Fig.1. Diagram of the implementation of the differential principle of AR of OCPLs in JSC "UEC"

This technical solution is implemented on the differential current principle using optical CTs. At the same time, despite the compactness of the solution (using one terminal), it is necessary to install additional communication equipment, organize a fiber-optic communication line, install optical sensors, which makes it quite expensive. The use of this method of AR of OCPL depends on the operating conditions of OCPL, and sometimes it does not allow achieving all the purposes set.

In PJSC "MOESK", R&D has been implemented on the creation of an automatic reclosing device for OCPL with the functions of determining the fault location (FL) at the OCPL, as well as monitoring the state of the faulted overhead section during the reclosure process [3,4].

In the prototype AR device of OCPL, traditional and innovative algorithms were implemented:

- FL by parameters of emergency mode;
- location method (active sounding);
- wave method - wave fault location (WFL).

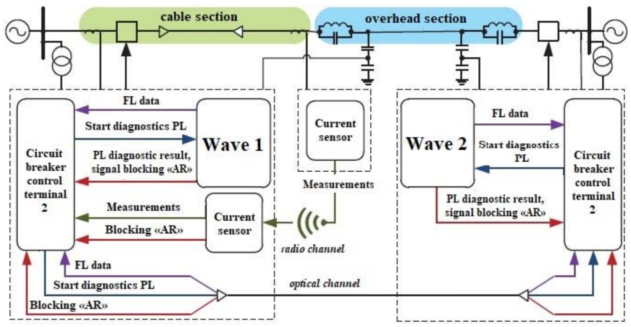

Fig.2. Connection diagram of the prototype AR device of OCPL in PJSC "MOESK" [3]

However, a prototype of such an AR device is rather difficult to implement, since it includes devices for wave determination of places of fault (FL) and active sensing devices using complex modulated high-frequency signals.

A method is known abroad [5] based on a differential optical system for identifying a malfunction at OCPL (Fig. 3).

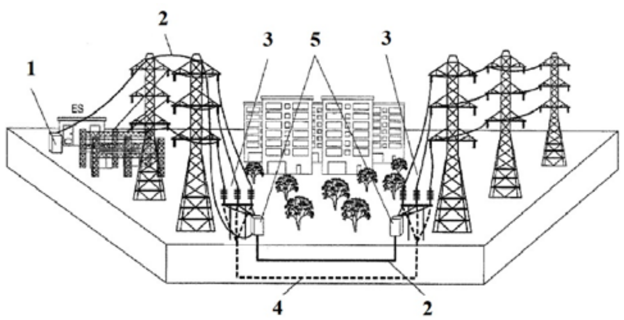

Fig.3. Diagram of the differential-optical system of AR of OCPL [5]

In fig. 3: 1 - fault recognition terminal, 2 - single-mode optical fiber in overhead lines, 3 - overhead section, 4 - cable section, 5 - junction boxes.

The system is based on the classical differential principle. The differential measurement of the electric current takes place at two different points in the tested section and is compared (in the fault recognition terminal - 1). Remote measurements are sent to the specified fault recognizer via fiber optic. The two points at which measurements are made can be several kilometers apart. If a short circuit occurs, the currents passing through the two measuring points are different, and this difference is detected by a short circuit recognition device, in which a decision is made to disconnect the OCPL.

The specified technical solution is similar to that implemented in JSC "UEC" and has similar disadvantages.

Method of automatic reclosing of combined overhead and underground cable power lines using a cable sheath

When the OCPL includes only cable entries at the substation or there are cable inserts on the overhead power lines with the corresponding transition points at the junction of the cable and overhead sections, the task is greatly simplified.

In this case, it is advisable to monitor only the condition of the high-voltage cable. The simplest technical solution is to apply a special signal to the metal sheath of the cable. Fault to a high-voltage cable is accompanied by arc faults with insulation failure and overlapping on the metal sheath of the cable. In this case, a special signal is sent to the cable cores. The fact of the presence of a special signal on the cable veins indicates fault to the cable section of the OCPL. In case of fault in any of the overhead sections, a special signal on the cable cores will be absent. Thus, absolute selectivity is achieved in determining the faulted overhead or cable section of the power transmission line.

There is a known method in which the AR of the OCPL is blocked due to the sensor of the total grounding current of the screens of the cable section [6]. The principle of the method is also based on the differential method. The only difference is that the currents are measured on the cable shields.

The method of AR of the OCPL proposed by the authors can be implemented by the device shown in Fig. 4 [7].

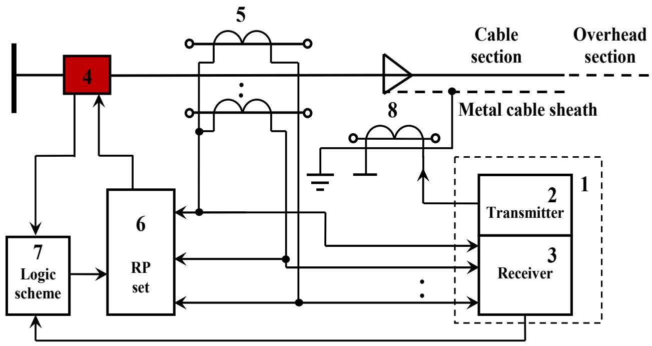

Fig.4. Method of AR of the OCPL using a cable sheath

The device (Fig. 4) includes: transceiver - 1, consisting of a transmitter - 2 and a receiver - 3; switch - 4; current transformers - 5; relay protection set - 6; logic scheme - 7; special signal transformer - 8.

A supply voltage is supplied to the transceiver - 1, which ensures the functioning of the transmitter - 2 and the receiver - 3. Transmitter - 2 generates a special continuous signal (for example, a frequency of 200 Hz), which is fed through the special signal transformer - 8 to the metal sheath of the cable. A conventional current transformer can be used as a special signal transformer - 8, and a special signal from the output of the transmitter - 2 is fed to the secondary winding of the current transformer.

Thus, the load of the transmitter - 2 is one of the windings of the transformer of the special signal - 8, the other winding of which is included in the ground circuit of the metal sheath of the cable. A special continuous signal of the transmitter frequency - 2 circulates through the metal sheath of the cable.

In the normal operation of the OCPL, as well as in the case of a short circuit in the overhead sections of the power transmission line, since the internal insulation of the cable is not faulted, the special frequency signal of the transmitter - 2 does not go either to the cable cores or through the current transformers - 5 to the input of the receiver - 3. Accordingly, the control signal from the output of the receiver - 3 is not supplied to the input of the logic circuit, therefore, from the output of the logic circuit - 3, a permissive signal to the AR of the OCPL is issued to the set of relay protection - 6. Therefore, in case of fault in the overhead section of the OCPL, its automatic reclosure occurs.

With a short circuit on the cable, the internal insulation of the cable breaks through to the metal sheath. A special signal from the output of transmitter - 2, through a special signal transformer - 8, the metal sheath of the cable, the core(s) of the cable, the current transformer - 5 is fed to the input of the receiver - 3. The receiver - 3 captures the special signal of the transmitter - 2 and sends the control signal to the logic scheme - 7 In the presence of a signal to open the switch - 4, as well as an incoming control signal from the output of the receiver - 3, the logic scheme - 7 issues a signal to prohibit the AR of the OCPL to the relay protection set - 6, since the receiver - 3 has detected a cable fault.

Thus, the proposed method of AR of the OCPL provides the issuance of a permitting signal for reclosing if the fault occurred only on the overhead sections of the transmission line and prohibits automatic reclosing in case of fault to the cable sections.

Method of automatic reclosing of overhead and underground cable power lines based on the traveling waves recognition

In contrast to [3,4], it is much easier to implement the method of AR of the OCPL using one-sided wave FL with the formation of "traveling waves patterns" (TWP) of power transmission lines [8-12]. Traveling wave pattern can be obtained from the time diagram of the results of the re-reflections of waves arising in the place of fault from the inhomogeneities of the power transmission line. An example of the formation of such a pattern by a one-sided FL device is shown in Fig. 5. The figure also shows the OCPL, as well as the dependence of the re-reflections of voltage waves (currents) on time.

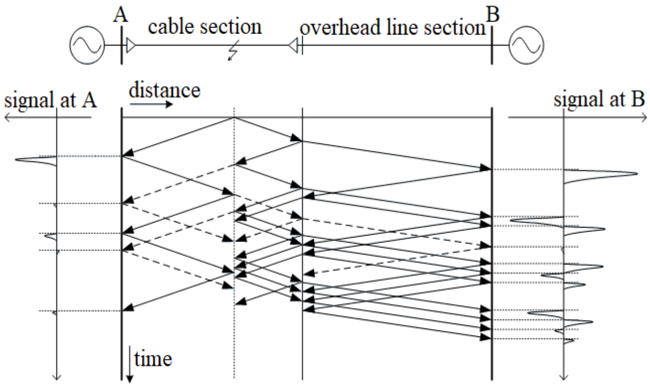

Fig.5. Formation of the traveling wave process

Obviously, strictly defined traveling waves patterns will correspond to fault at various distances from the ends of the power transmission line. That is, certain dependences of voltages (currents) in time. Examples of such patterns for the power transmission line model at different distances from substation B are shown in Fig. 6.

The place of fault to the OCPL can be recognized by the characteristic TWP obtained at one of the ends of the power transmission line. Recognition of TWP is advisable to implement based on the calculation and analysis of mutual correlation functions [13, 14]. In this case, a traveling wave pattern from fault at one of the ends of the power transmission line is recorded, and then cross-correlation functions are calculated with all possible patterns (corresponding to the places of fault) (Fig. 6). The maximum value of the correlation function will correspond to the TWP (fault location) of the power transmission line, which is most similar to the wave pattern recorded as a result of the current fault to the power transmission line. That is, according to the maximum value of the correlation function of TWP, it is possible to implement the FL procedure for power lines. The database of traveling waves patterns (similar to Fig. 6) for FL power lines can be formed using preliminary simulation.

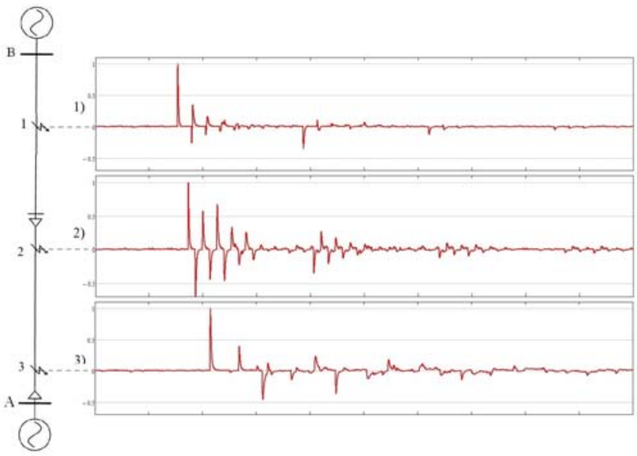

Fig.6. Overhead and underground cable power lines scheme and "traveling waves patterns" (TWP)

The proposed method of AR of the OCPL can be implemented by a device in accordance with the diagram (Fig. 7).

The device (Fig. 7) contains: connection block - 1; block of wave determination of fault to power lines - 2; information processing block - 3; combined overhead and underground cable power lines - 4.

Connection block - 1 can be CTs or high-frequency (HF) power line connections.

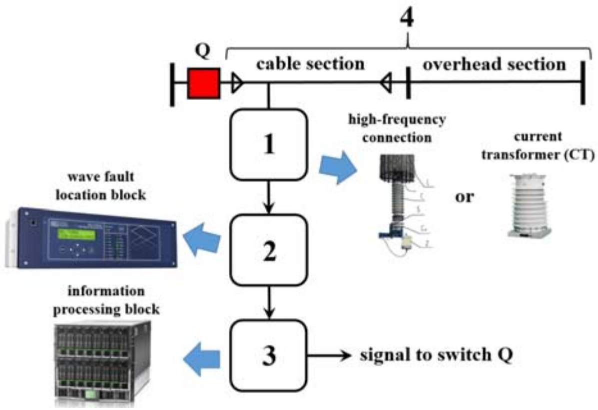

Fig.7. Implementation diagram of the AR of the OCPL device

It should be noted that high-frequency connections can be performed in accordance with the circuit solutions [15], and the blocks of wave fault location on power lines - 2 in accordance with circuit solutions, for example, the Canadian company Qualitrol [16] or SEL [17].

Before the implementation of the method of AR of the OCPL, simulation of all kinds of faults at various distances from the ends of the power transmission line is performed to obtain TWP. Based on the resulting set of patterns, a database of TWPs is formed, each of which is individual and corresponds to a strictly defined place of fault to power lines. The database of wave patterns is divided into two parts (groups) corresponding to overhead and cable sections of power transmission lines. When a power transmission line fault is assigned to a group of cable sections, a prohibiting signal is issued to the AR of the OCPL, otherwise the AR is allowed. The database of TWPs before the implementation of the AR of the OCPL method is written into the information processing unit - 3.

Traveling waves patterns in case of fault to power lines can be represented as time-varying dependences of currents and voltages. For example, if a CT acts as a connection block - 1, then the wave patterns correspond to the dependences of the current in time. If, for example, HF connection acts as a connection block - 1, then the wave patterns correspond to the voltage dependences in time.

The proposed method for AR of the OCPL uses one-sided registration of electromagnetic waves and recognition by one-sided TWP. Such a technical solution significantly simplifies the AR of the OCPL and does not require the use of complex and expensive equipment, as well as high-speed communication channels, as in [3,4]. In this case, blocks 1-3 of the device for the implementation of the proposed method can be installed on either end of the transmission line, taking into account the fact that the database of TWPs should be generated based on the specific location of the equipment installation.

In the event of fault at OCPL - 4, the electromagnetic wave is recorded by unit - 2, where a TWP is formed, which is fed to the information processing block - 3 to implement the recognition procedure. In block - 3, the signal received from block - 2 is compared with each TWPs from the database by determining the maximum cross-correlation function, which is an indicator of the location or area of fault at the OCPL. The place of fault corresponding to the TWP from the database unambiguously characterizes the faulted area (cable or overhead) and the estimated distance to the place of fault. Further, from block - 3, a prohibiting signal is issued to the AR of the OCPL, if the fault has occurred at least on one of the cable sections.

Despite the one-sided execution, the prototype method presupposes rather complex algorithms for processing "traveling waves patterns" associated with the implementation of their recognition procedures and requiring high performance, processing time and the cost of computing facilities. On the other hand, the prototype method has low noise immunity, since "traveling waves patterns", distorted by interference, can lead to recognition errors and, accordingly, to malfunctioning of the automatic reclosure device of the OCPL.

Automatic reclosing method for OCPL based on the analysis of the front of an incident traveling wave

An electromagnetic wave, propagating along power lines with inhomogeneous sections, such as OCPL, undergoes additional attenuation due to the mismatch of the wave impedances of different sections. Depending on the faulted section of the OCPL and the place of fault, electromagnetic waves undergo different attenuation on the way to the substation and the place of measurement. By measuring the amplitude of the front of the wave signal, it is possible to indirectly determine the faulted area. However, on the basis of only one-sided measurements, it is difficult to draw a conclusion about the faulted area due to the dependence of the front amplitude on the voltage phase at the moment of short-circuit and transient resistance. It is advisable to use measurements at two ends of the power transmission line, and the ratio of the signals of currents or voltages at the two ends of the OCPL makes it possible to practically selectively determine the faulted area [11, 18].

In Fig. 8 shows the junction of two sections with different wave impedances (the place of discontinuity). Part of the wave energy is reflected and begins to propagate in the opposite direction (a reflected wave is formed), and the other part passes beyond the place of discontinuity (transmitted wave).

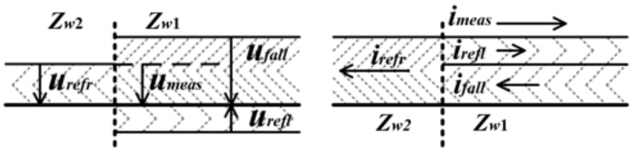

Fig.8. Relations of voltages and currents of TWs at the line discontinuity [11]

In Fig. 9 shows an overhead line with a cable insert at a distance from both substations A and B (OL-CL-OL configuration). Each section (m-th section) has its own parameters: characteristic impedance $Z_{c.n}$ and attenuation. The attenuation can be expressed in terms of the attenuation coefficient of the m-th section ($k_{A.n}$), which characterizes the ratio of the amplitude of the incident voltage TW at the end of the m-th section to the signal amplitude at the beginning of the section. In this case, $k_{A.n}$ is determined by the equation:

(8) $$k_{A.n} = e^{-0.115 \cdot \alpha_n \cdot L_n},$$

where α_n - the specific attenuation coefficient for the corresponding wave propagation mode of the m-th section of the OCPL (dB / km); L_n - the length of the n-th section of the OCPL.

Let us determine the voltage of the incident wave front at the ends of the OCPL in case of faults in various sections (Fig. 9).

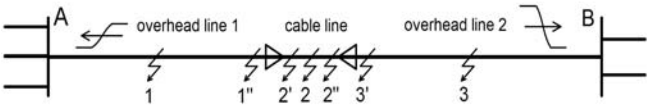

Fig.9. Schematic representation of the OCPL with different fault locations

For the 1-st section of the OCPL, the following equations are obtained (9)-(11):

(9) $$u_{fall.A} = u_0 \cdot k_{A.1}^{\,l_{F.1}/L_1};$$

(10) $$u_{fall.B} = u_0 \cdot k_{A.1}^{\,(L_1 - l_{F.1})/L_1} \cdot k_{T.1-2} \cdot k_{A.2} \cdot k_{T.2-3} \cdot k_{A.3};$$

(11) $$\frac{u_{fall.A}}{u_{fall.B}} = \frac{1}{k_{T.1-2} \cdot k_{T.2-3}} \cdot \frac{1}{k_{A.2} \cdot k_{A.3}} \cdot k_{A.1}^{\,(2 \cdot l_{F.1} - L_1)/L_1},$$

where $k_{T.n\text{-}m}$ - the voltage transmission coefficient of the TW transmitted beyond the junction of m-th transmission line section and n-th transmission line element (section). It assumes the TW propagates from m-th section to n-th element. By the element of transmission line is meant the fault location, substation buses or section of transmission line; $l_{F.n}$ - distance to the fault location from the beginning of the m-th section of transmission line [11].

For the 2nd and 3rd sections of the OCPL, equations (12) and (13) are obtained, respectively:

(12) $$\frac{u_{fall.A}}{u_{fall.B}} = \frac{k_{T.2-1}}{k_{T.2-3}} \cdot \frac{k_{A.1}}{k_{A.3}} \cdot k_{A.2}^{\,(2 \cdot l_{F.2} - L_2)/L_2};$$

(13) $$\frac{u_{fall.A}}{u_{fall.B}} = k_{T.2-1} \cdot k_{T.3-2} \cdot k_{A.1} \cdot k_{A.2} \cdot k_{A.3}^{\,(2 \cdot l_{F.3} - L_3)/L_3}.$$

Equations (11-13) characterize the ratio of voltage signals at the terminals of the OCPL in case of fault in various sections. However, when fault location is close to the point of discontinuity, TWs, successively reflected from the discontinuity and from the fault location, arrive at the measurement point in a very short time after the first TW.

Therefore, in such cases, these additional reflected TWs will interfere, and the measurement of the TW amplitude will be affected.

On the basis of the obtained ratios at each section of the OCPL, it is possible to construct a dependency graph of the ratio $U_{fall.A}$ / $U_{fall.B}$ on the fault location. Fig. 10 a, b shows such plots for 220 kV OCPL (configuration: OL-CL-OL) for various ratios of lengths of sections. The average values of the parameters in the frequency range 10-100 kHz were for the first interphase mode: Z_{c1} = 370 Ohm, Z_{c2} = 30 Ohm, Z_{c3} = 370 Ohm, and α_1 = 0.023 dB/km, α_2 = 1.1 dB/km, α_3 = 0.022 dB/km. For convenience, Fig. 10 shows the function of the decimal logarithm of the ratio of $U_{fall.A}$ / $U_{fall.B}$.

Analyzing Fig. 10. a, b, it can be noted that when passing through the overhead-cable transition, the voltages relation undergoes a jump, which value depends on the ratio of the characteristic impedances of the corresponding sections and does not depends on the lengths of these sections. It should be noted that the presence of another discontinuities in the power transmission line sections (for example, the phase transposition of the OL or the shields transposition of the CL) will distort the dependence of Fig. 10. Therefore, for the formation of complex dependencies, taking into account all the discontinuities of power lines, it is advisable to use simulation.

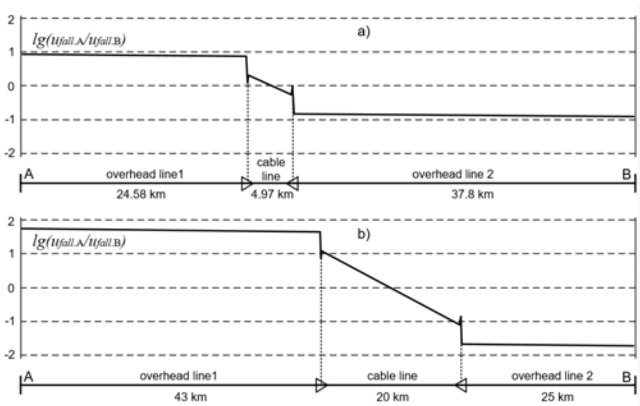

Fig.10. The ratio of the amplitudes of the incident TWs voltages at two ends of the OCPL from the fault location [11]

In the immediate vicinity of the cable-overhead transition, there is a zone of uncertainty, in which the short-circuit on the overhead and cable sections practically does not differ without the use of additional recognition methods. Therefore, when choosing the triggering parameters of the algorithm for recognizing the faulted section of the high-voltage line, it is advisable to refer the zone of uncertainty to the cable section to prevent automatic reclosing in case of fault to the cable sleeve and near it. The carried out simulation of the OCPL and the corresponding algorithm for recognizing the faulted area showed that the zone of uncertainty depends on the methods of digital filtering of current and voltage wave signals, as well as the transient characteristics of the connection device (measuring transformers).

It is convenient to display the above ratios in the two-dimensional region $|U_{fall\ A}|$, $|U_{fall\ B}|$, as shown in Fig. 11. In this case, the area of the first quadrant is divided by beams into zones corresponding to the sections of the OCPL. The choice of parameters for the procedure for recognizing the faulted area is reduced to calculating the tilt angles (θ1 and θ2) of the indicated rays (Fig. 11).

The structural diagram of the proposed method is similar to Fig. 7. Only sets of equipment 1, 2 and 3 will be installed at the ends of the OCPL with the organization of a communication channel between them.

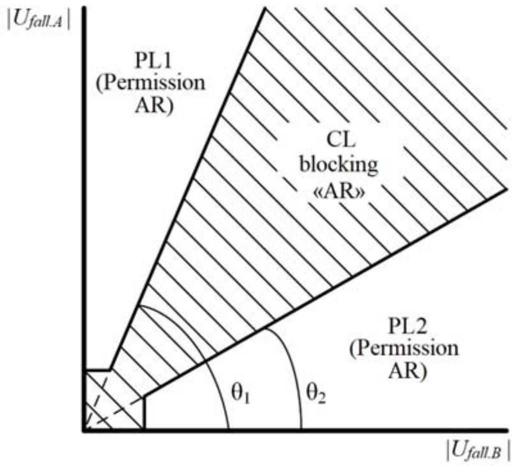

Fig.11. Two-dimensional representation of $U_{fall.A}$ / $U_{fall.B.}$

After the implementation of digital signal processing operations, the maximum values (amplitudes) of signals (ΔU_{max}) are recorded at the ends of the transmission line, which correspond to the fronts of the first waves, for example, voltage. The values measured and recorded in this way at the ends of the transmission line (ΔU_{Amax} and ΔU_{Bmax}) are transmitted via the communication channel between substation A and substation B (Fig. 9).

After that, there is an indirect assessment of the distance to the fault in relation to the voltage amplitudes (ΔU_{Amax} and ΔU_{Bmax}) and checking whether the fault site has entered the AR blocking zone (Fig. 11). Depending on the result, a prohibiting signal is issued from the output of the information processing block 3 to re-enable the cable-overhead transmission line, if fault has occurred at least on one of the cable sections. Additionally, from another output of the information processing block 3, information is given on the estimated distance to the place of fault, determined on the basis of the dependence (Fig. 11).

It is important to note that the signal allowing the AR of the OCPL and information about the place of fault is generated at both ends of the transmission line by information processing blocks 3. Therefore, taking into account the communication channel, they can be used for redundancy and increasing the reliability of the AR of the OCPL, including in conditions of interference.

Conclusion

Three promising ways of implementing automatic reclosing (AR) of combined overhead and underground cable power lines (OCPL) are considered.

The first method, using a metal sheath of cables, is quite simple and is suitable mainly in the case when the OCPL includes only cable entries to the substation.

The second method based on the analysis of "traveling waves patterns" shows good results, however, it involves rather complex algorithms for processing "traveling waves patterns" associated with the implementation of procedures for their recognition and requiring high performance, processing time and cost of computing resources.

The third method, based on the analysis of the front of the incident electromagnetic wave, is able to determine the presence of fault in the zone of the cable-overhead transition (zone of uncertainty), and also does not contain complex digital signal processing operations, which simplifies the computational procedure.

This work has been performed with the support of Research and Educational Center of Nizhny Novgorod region in the framework of the agreement No 16-11-2021/50.

***Authors**: Doctor of Technical Sciences, Professor, Kulikov Alexander Leonidovich, Professor of the Department of Electric Power Engineering, Power Supply and Power Electronics, NSTU n.a. R. E. Alekseeva, E-mail: inventor61@mail.ru; Ph.D., Loskutov Anton Alekseevich, Associate Professor of the Department of Power Engineering, Power Supply and Power Electronics, NSTU n.a. R. E. Alekseeva, E-mail: loskutov.nnov@gmail.com; Pelevin Pavel Sergeevich, Assistant of the Department of Electric Power Engineering, Power Supply and Power Electronics, NSTU n.a. R. E. Alekseeva, E-mail: pelevin.p.s@mail.ru; Ph.D., Kryukov Evgeny Valerievich, Associate Professor of the Department of Power Engineering, Power Supply and Power Electronics, NSTU n.a. R. E. Alekseeva, E-mail: kryukov@nntu.ru; Doctor of Technical Sciences, Professor, Loskutov Aleksey Borisovich, Professor of the Department of Electric Power Engineering, Power Supply and Power Electronics, NSTU n.a. R. E. Alekseeva, E-mail: loskutovab@mail.ru.*

REFERENCES

[1] Electrical Installation Rules (PUE), 7th edition (approved by the Order of the Ministry of Energy of 08.07.2002. No. 204
[2] https://madeinrussia.ru/en/news/2478
[3] Dogadkin D., Marin R., Shirshova E., Ismukov G., Kulikov A., Lint M., Podshivalin A. Device for automatic reclosing of cable-overhead power lines of megacities // *Electricity. Transmission and distribution*. No. 5 (38). 2016. p. 114-119
[4] Patent for a useful model of the Russian Federation No. 1655635 Device for automatic reclosing of cable-overhead power lines H02H03 / 06, G01R01 / 00, publ. 10/27/2016, No. 30
[5] U.A. Gallastegi, “Optical system for identifying faults in mixed power transmission lines,” Patent WO2015033001 (A1), 2015
[6] Patent for invention No. 2669542 System of selective blocking of automatic reclosing on combined cable-overhead power lines H02H03 / 06, publ. 10/11/2018, No. 29
[7] Patent for invention No. 2663413 Method of automatic reclosing of cable-overhead power lines H02H03 / 06, H02H7 / 26, publ. 08/06/2018, No. 22
[8] Kulikov A., Loskutov A., Pelevin P. Methods for implementing of the single-ended traveling wave fault locating on the transmission lines based on traveling wave pattern recognition *// 2018 International Multi-Conference on Industrial Engineering and Modern Technologies, FarEastCon*. 2018. pp. 1-6.
[9] Kulikov A., Loskutov A., Pelevin P. Application of Correlation Methods for Traveling Wave Fault Locating and Automation of Intelligent Electrical Networks // *2019 International Multi-Conference on Industrial Engineering and Modern Technologies, FarEastCon. 2019.*
[10] Loskutov A., Pelevin P., Sharafeev, T. Improving the reliability of combined overhead and cable power lines by organizing smart autoreclosing // *E3S Web of Conferences*, 2019, 139, 01062
[11] Kulikov A., Loskutov A., Pelevin P. The Method of Faulted Section Estimation for Combined Overhead and Cable Power Lines Using Double-Ended Measurement // *Proceedings - 2020 International Ural Conference on Electrical Power Engineering, UralCon 2020*, 2020, pp. 70–75, 9216299
[12] Patent for invention No. 2658673 Method of automatic reclosing of cable-overhead power lines H02H03 / 06, G01R31 / 08, publ. 06/22/2018, No. 18.
[13] Shirman Y.D., Gorshkov S.A., Leshchenko S.P., Bratchenko G.D., Orlenko V.M. Radar recognition methods and their modeling. - Foreign radio electronics, 1996, No.11, pp. 3-63.
[14] Kulikov A.L., Loskutov A.A., Pelevin P.S. Algorithm for identification of a damaged area on cable-overhead power lines based on the recognition of wave portraits *// Electricity*. 2018. No. 3. pp. 11-17.
[15] Mikutskiy G.V., Skitaltsev V.S. High-frequency communication over power lines. - M .: Energy, 1969.
[16] http://www.qualitrolcorp.ru
[17] http://www.selinc.com
[18] Patent for invention No. 2719763 Method for automatic reclosing of cable-overhead power lines H02H03 / 06, publ. 04/23/2020, No. 12.