TESTING OF 6-500 kV CABLES IN POLYMER PIPES

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In recent years, the laying of 6-500 kV cable lines in polymer pipes has become widespread. This solution allows to minimize the amount of excavation, to cross various communications and barriers, to provide mechanical protection of cables. However, as experience has shown, polymer pipes have a significant drawback – they prevent to identify the presence of defects in the cable outer sheath and determine the exact location of these defects along the line route.

Keywords: cable line, cross-linked polyethylene, cable screen, outer sheath, sheath testing, sheath defect locating

INTRODUCTION

When laying cable lines (CL) of rated voltages 6-500 kV, cables with insulation made of cross-linked polyethylene (XLPE) are currently mainly used. The following designs of such cables are most common:

– single-core for 6-500 kV networks (Fig.1a);
– three-core for 6-35 kV networks (Fig.1b).

For all cables with XLPE insulation, an important design element is the outer sheath, usually made of polyethylene or PVC. The thickness of the sheath, as a rule, is 4-6 mm, and its main function is to seal the cable in order to prevent water penetration into the XLPE. It should be understood that a number of other methods can be used for sealing, but they are not the main ones, but only complement the cable sheath.

Increased attention to the protection of the cable from water penetration is due to the fact that water molecules, once between the molecules of the XLPE, distort the electric field and over time lead to the appearance of defects in the insulation, which are called «water trees» and are able to bring the insulation to a complete breakdown. For this reason, it is important to periodically check the integrity of the outer sheath, timely identify all the facts of its damage, find the location of defects along the route of the line and eliminate them.

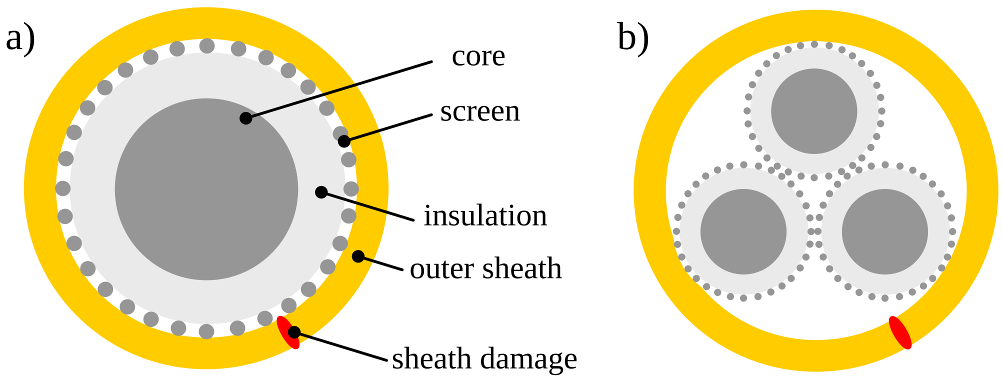

Fig.1. Design of cables with XLPE insulation:
a) single-core cable; b) three-core cable

The possibility of correct testing and prompt searching for places of cable outer sheath damage largely depends on the conditions of cable laying. It is known that when laying in the air, where the cable is surrounded by a dielectric medium, even serious sheath damage can go unnoticed, whereas when laying in the ground, such problems do not arise due to the conductive properties of the soil and the moisture present in it. However, unfortunately, nowhere in the publications and standards does it indicate that problems similar to the air dielectric medium arise when laying cables in the ground in polymer pipes.

The new article examines why the placement of cables in polymer pipes seriously hinders both the identification of cable outer sheath damages and locating for places along the CL route where these damages occurred. Thus, the article is intended to draw readers' attention to the fact that the widespread use of polymer pipes in the construction of CL is convenient and profitable for installation organizations and pipe manufacturers, but for the operation services of network companies it can turn into an unsolvable problem of sheath testing with the resulting negative consequences for the main cable XLPE insulation.

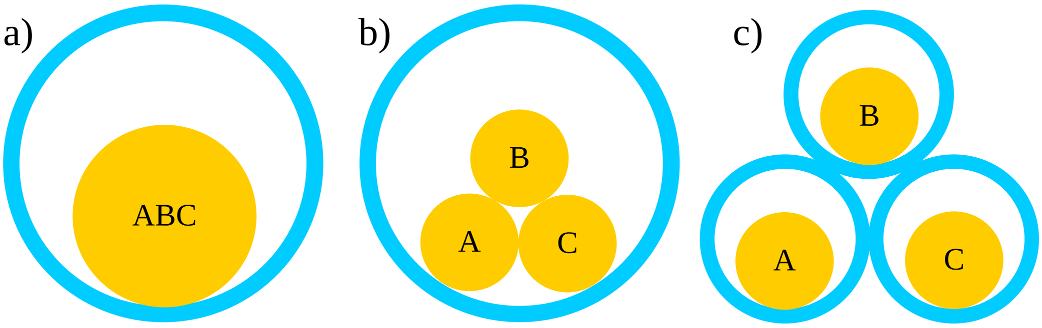

Fig.2. Options for placing cables in pipes:
a) three-phase cable;
b) three single-core cables in a common pipe;
c) three single-core cables in separate pipes

LAYING CABLES IN PIPES

The use of polymer pipes for laying CL is regulated by many documents, for example, a relatively new Standard [1], where pipes are considered in clause 8.6. There is a whole list of cases when the placement of cables in pipes is directly prescribed by one or another of the norms: for example, the organization of cable entry into cable rooms of switchgear in electrical stations and substations; the creation of pipe blocks when laying a large number of cables together; performing the intersection of various communications. Traditionally, in 6-35 kV networks, all three phases are laid in a common pipe (Fig.2a and Fig.2b). For 110-500 kV networks, on the contrary, phase-by-phase placement is used in pipes located in the ground in a bundle (Fig.2c) or at a distance from each other.

Asbestos and metal pipes had a number of serious disadvantages that limited their use for laying cables – for example, they were not flexible, and therefore could only be used on straight sections of the CL route. Asbestos pipes were pricked, had an abrasive effect on the outer sheath of the cable when it was pulled, did not allow the pipes to be hermetically joined in order to avoid silting them. As for the metal pipes, they had a high weight and cost, were corroded. The appearance of flexible polymer pipes, devoid of many disadvantages inherent in asbestos and metal pipes, has opened up wide opportunities for design and installation organizations to use such pipes in the construction of CL, not only within the framework of fulfilling the requirements of regulatory documents, but also far beyond them.

The construction of a 6-500 kV CL in polymer pipes involves several stages. First of all, individual pipes (usually up to 12-13 m long) are welded together end-to-end to form a single monolithic channel of the required length. Further, the pipe channel (channels) prepared in this way is placed in the ground, after which the cables are tightened into it. Two methods of placing polymer pipes in the ground are most common:

– open at the bottom of the trench (Fig.3a);
– closed by horizontal directional drilling (HDD, Fig.3b).

Trench pipe laying (Fig.3a) is very widely used due to the fact, for example, that at the same time the requirements for the quality of preparation of the trench bottom and for the soils used for backfilling are reduced. In addition, it is believed that during operation, the pipe will provide certain mechanical protection of cables in case of "careless" earthworks near the route. The pipe arrangement depths are usually H_1>0.7 m for 6-35 kV cables and H_1>1.5 m for 110-500 kV cables.

The widespread use of the HDD method (Fig.3b) when laying CL is explained by the fact that with HDD it is possible to minimize the amount of excavation work and related approvals in various instances. Now the length of single HDD sections reaches 300-500 m, and the factors constraining the further growth of the length, perhaps, is only the limitation of the construction length of the cable and the need to organize flat areas outside the pipes for the installation of connecting couplings (cable joints). HDD is characterized by depths H_1>0.7÷1.5 m and H_2>3÷10 m.

At the ends of the pipe sections according to [1], the following are installed:

– funnels that protect the cable sheath from the impact of the sharp edge of the pipe;
– seals that prevent silting of the pipe and thereby ensure the possibility of unhindered cable removal from the pipe for the purpose of its repair or complete replacement.

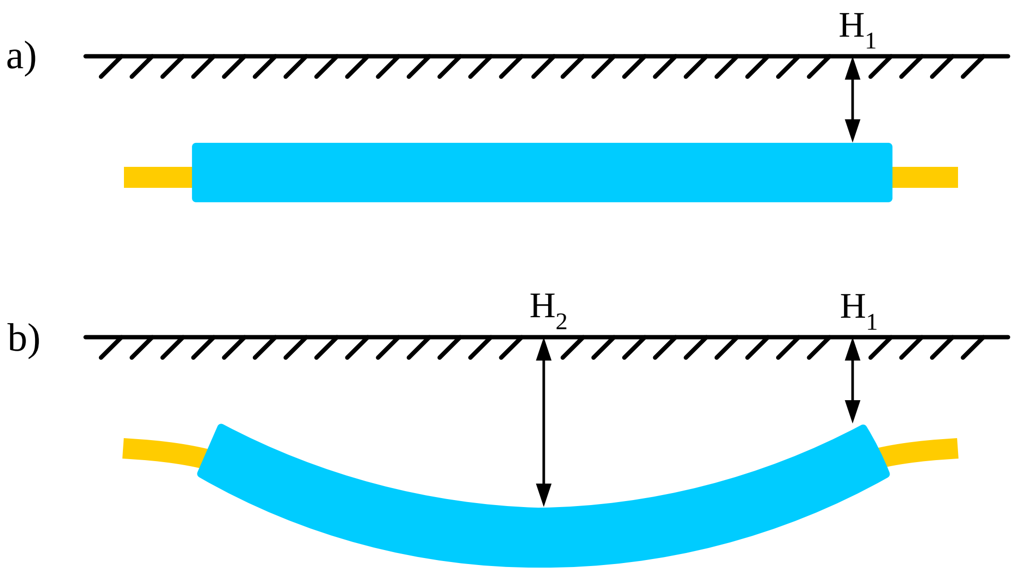

Fig.3. Laying a cable in a polymer pipe in the ground:
a) the pipe is placed at the bottom of the trench;
b) the pipe is tightened into the ground by the HDD method

CABLE SHEATH TESTS

Checking the integrity of the cable outer sheath is carried out as part of the acceptance tests of the CL, as well as periodically during operation of the CL. The test is carried out on a disconnected cable where, after grounding the cable metallic screen, a DC test voltage of 10 kV is applied to the cable (between screen and ground) for a time of 1 min. Earlier in the article [2] it was shown that if the cables are single-core and their outer sheath protected by metal-oxide surge arresters (MOA) with an operating voltage of 8-9 kV installed between their screens and ground, then it is not necessary to turn off such MOAs during the tests – this significantly reduces the time for preparing the circuit for sheath testing.

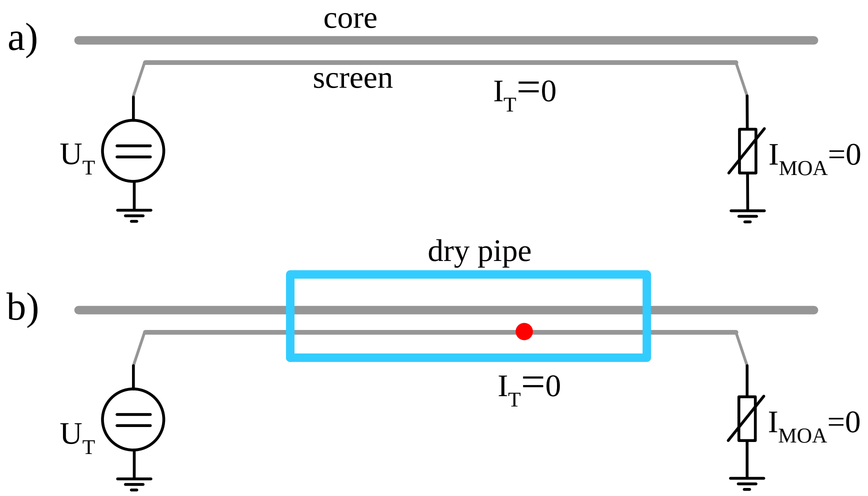

Fig.4. Cases when the cable will *successfully pass* the outer sheath tests:
(a) – the cable is in the ground; the sheath is not damaged;
(b) – the cable is in a dry pipe; the sheath is damaged, but it cannot be detected.

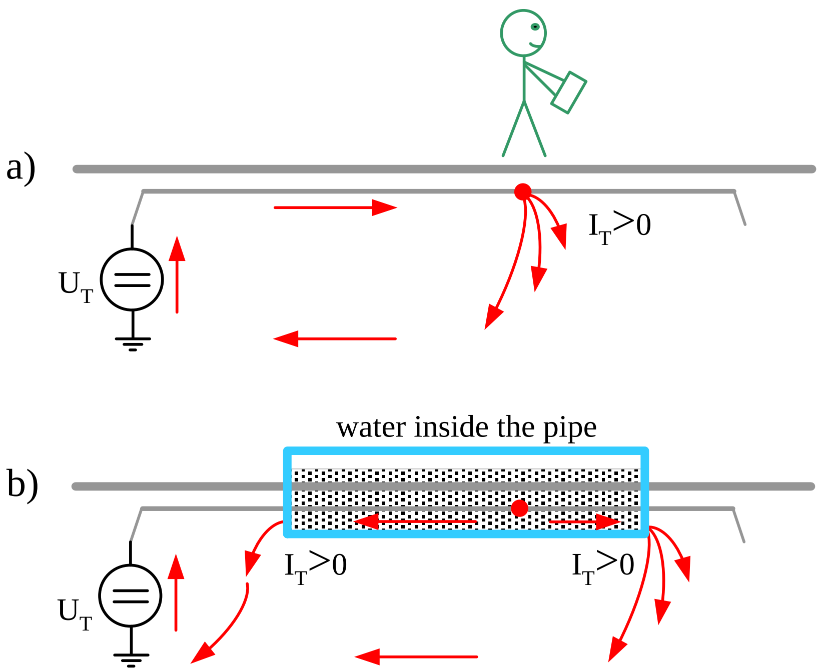

Fig.5. Cases when the cable *will not successfully pass* the outer sheath test:
(a) – the cable is in the ground; the sheath is damaged;
(b) – the cable is in a wet pipe; the sheath is damaged, and it was found due to water in the pipe.

If the testing equipment supplying the voltage to the screen detects the absence of a test current (I_T=0, Fig.4a), the staff will conclude that both the cable outer sheath and the on-screen MOA have no dangerous damage. However, if there are pipe sections of the route, such a conclusion may be incorrect.

If the cable has sections laying in pipes, then the absence of a test current I_T=0 will not necessarily mean that the cable sheath does not have critical damage. The fact is that polymer pipes isolate the cable from the surrounding ground, and even if there is noticeable sheath damage, the test current will not be able to exit the screen into the ground (Fig.4b).

The possibility for current I_T to exit the cable screen through the damaged sheath into the ground occurs when the cable is laid directly in the ground (Fig.5a), or when the cable is laid in a pipe that is wet inside to a degree sufficient to ensure the connection of the damage point with at least one of the pipe ends (Fig.5b). In both these cases, the personnel will record the test current I_T>0 and conclude that it is necessary to find an exact place along the CL route where there is the cable outer sheath damage.

FILLING THE PIPE WITH WATER

According to regulatory document [1], polymer pipes are always sealed at each end to exclude silting, but in practice this also slows down the process of filling the pipe with groundwater or even makes such filling impossible. Considering the above, it is highly likely that at the time of the CL acceptance tests, the pipe will have an amount of water insufficient to ensure the output of test current from the cable screen through the damaged sheath into the ground. Therefore, the staff will fix I_T=0, the line will be recognized as serviceable, and the installation company will receive a signed certificate of work performed, although it commissioned the line with sheath damage (damage occurred either during the production of the cable at the factory, or during its installation).

When laying pipes into the ground, even before the cables are tightened in them, a certain amount of soil and water will certainly get into the pipes, which, after pulling the cable and sealing the ends, are permanently closed inside the pipe. If enough water has got into the pipe so that its ends are reliably wetted, then, of course, the fact of sheath damage will be detected at the stage of acceptance tests (Fig.6a and Fig.6b), and the installation organization will have to eliminate it at its own expense.

If there is not enough water (Fig.7a), then it will not be possible to establish the fact of outer sheath damage within acceptance tests, but strictly speaking, in this case there is no special danger of water penetration into the XLPE insulation. During operation, even if the filling of the pipe will occur, due to the absence of a height difference, it will pass evenly along the entire pipe, which means that although the danger to the cable increases, but the conditions for detecting the fact of the outer sheath damage will also improve. Consequently, sooner or later, during the next check of the outer sheath, the fact of its damage will still be established (Fig.6a). Alas, the grid company will have to repair the damage at own expense, because many years may pass from the date of the start of CL operation, and the warranty obligations of the cable manufacture and the installation organization will have time to stop.

Much more serious consequences will arise in the case of horizontal directional drilling (HDD) situation (Fig.7b), where after the CL installation is completed, due to the height difference, a significant volume of water was "locked" in the lower part of the sealed pipe.

Since the ends of the pipes are not wetted with water, then I_T=0, and therefore the acceptance tests of the CL will be successful. Further, as the CL is operated, it may turn out that due to the high-quality sealing of the ends, the volume of water will not increase, the ends of the pipe will remain dry, sheath damage will not be detected even during regular periodic tests of the CL. At the same time, as can be seen from Fig.7b, from the first days after laying the cable with outer sheath damage lies in the water, nothing prevents it from water penetrating into the XLPE insulation, and the situation can persist for years.

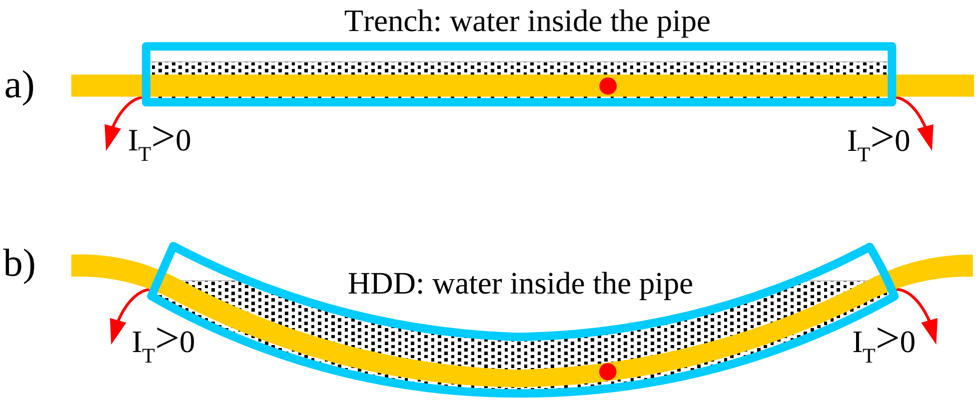

Fig.6. Cable sheath damage in the pipe, which *was detected*:
(a) – for the trench; (b) – for HDD

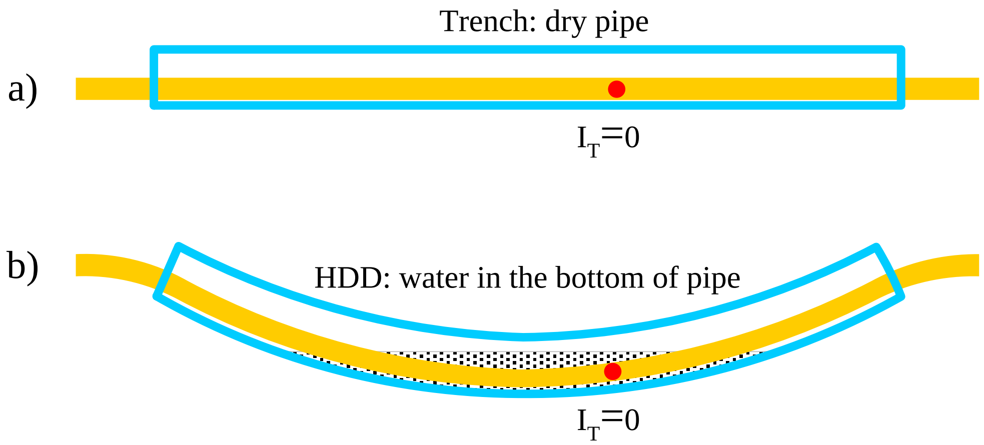

Fig.7. Cable sheath damage in the pipe, which *could not be detected*:
(a) – for the trench; (b) – for HDD.

SEARCH FOR CABLE SHEATH DAMAGE WHEN LAYING IN THE PIPE

In addition to timely detecting the fact of cable outer sheath damage, there is another problem – finding a specific place of the pipe section where this damage occurs. Finding the exact location is important, as it allows you to make a decision about the possibility of sheath repairing and about the optimal ways to perform it. Difficulties with repairs arise mainly if the damage occurred on a deep section of the HDD – in such a situation, a decision may be made to remove the cable from the pipe either to replace it with a new one, or to repair it on the ground surface for the purpose of subsequent tightening back into the pipe. As for the sections of trench laying, repair is carried out here by cutting out a small section of pipe and applying thermo-tube to the cable, but first you need to find the exact place of damage.

Finding the place of the cable outer sheath damage is difficult, since the polymer pipe releases a test current into the ground not where the damage is located, but along the ends of the pipe section (Fig.8a). Therefore, the standard step voltage method, which is based on finding the exit places of the current into the ground, will point to the ends of the pipe, but not to the specific outer sheath damage. Problems also arise when using the acoustic method, because the pipe muffles the sound from the pulsed sheath breakdown.

In order to find the place of cable sheath damage in the pipe section, the pipe should be opened sequentially and the cable should be in direct contact with the ground (Fig.8b). With the length of the pipe section reaching 300-500 m, the procedure of dividing the pipe into sections and consistently approaching the damage place may take a week or more. All this time, the CL will be disconnected, and the cable laboratory and its staff will be provided with hard work. It should be understood that the opening of the pipe should be carried out as carefully as possible, otherwise the saw can get through the cable and cause deep cuts to its sheath. After carrying out the procedure for searching for the outer sheath damage, the pipe will be divided into many sections, and it means the pipe will cease to be a solid sealed monolithic cable channel and will not be able to be reused in the case of network renovation and replacement of cables with new ones.

It is well known that cables equipped with an external semi-conductive layer are used to detect sheath damage when laying in the air, and hence a proposal may arise to use such cables on polymer pipe sections in the ground. Unfortunately, these cables are usually more expensive than traditional ones and are not always intended for laying in the ground, but another thing is more important – regardless of the type of cable sheath, the pipe will release a test current into the ground only at its ends, and it means that the procedure for dividing the pipe into sections will not be avoided in any way.

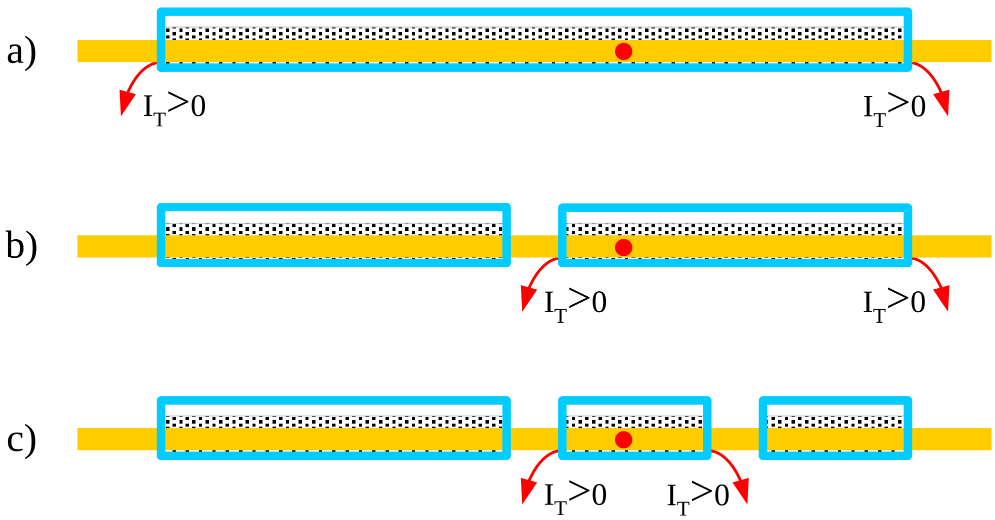

Fig.8. Locating procedure for the cable outer sheath damage in the pipe:
a) initial condition of the pipe;
b) the first pipe dividing;
c) the second pipe dividing

TEMPERATURE AND PARTIAL DISCHARGES CONTROL SYSTEMS

Modern CL, especially 110-500 kV classes, are equipped with expensive temperature monitoring and partial discharge control (PD) systems. Since the cable outer sheath damage doesn't cause an increase in the temperature of the XLPE insulation, temperature monitoring is useless for solving the problem of detecting the fact of outer sheath damage and locating its exact place along the CL route.

The PD measurement is carried out in the XLPE insulation of the cable when the network continuous operating voltage or high voltage from a third-party source is applied to it. At the time of the PD measurement, the cable metallic screens must necessarily be grounded. Since the cable screens are grounded, they have almost zero potential, and even if there is the cable sheath damage, there is no voltage on the screen, under the influence of which either some current could come out from the cable screen through the cable sheath damage or some PDs could occur in the cable sheath.

The PD control is able to detect cable outer sheath damage only indirectly – when, over the years of its existence, this damage will cause water penetration into the cable and give irreversible changes in the XLPE insulation itself.

CONCLUSIONS

Polymer pipes are increasingly used in the construction of modern 6-500 kV cable lines, and there is no alternative to such pipes in the foreseeable future. Despite the numerous advantages of placing cables in pipes, we should not forget about some of the features of this method of laying. In particular, it is important to understand that when carrying out acceptance and periodic tests of CL on pipe sections of the route, it is not always possible to identify existing cable outer sheath damage that are dangerous from the point of view of water penetration into the cable.

Considering the above, it makes sense for grid companies to pay increased attention to the input control of cable and pipe products entering the construction sites of 6-500 kV CL. It is also important to carefully monitor the progress of installation work and not to allow deviations from the requirements contained in industry regulations (for example, in terms of equipping the ends of pipes with end funnels). To reduce the risk of sheath injury during pipe laying, it can be recommended to use cables with a reinforced sheath.

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