HEAT RESISTANCE OF 6-500 kV CABLE LINES. REQUIREMENTS FOR POLYETHYLENE PIPES

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Many of 6-500 kV cable lines are laid in polymer pipes. Unfortunately, such pipes have insufficient heat resistance to use them for laying modern cables with insulation made of cross-linked polyethylene. What should be the requirements for cable pipes?

Keywords: cable line, cross-linked polyethylene, polymer pipe, polyethylene pipe, HDPE pipe, cable laying in pipe, pipe heat resistance.

Introduction

Cables with single-core cables with cross-linked polyethylene (XLPE) insulation are widely used in networks of all voltage classes – from 6 to 500 kV. Installation of such cables is carried out in various ways, one of which is laying in pipes. After performing the pipes route (trench or drilling channel or punctures), pipes are placed into it, cables are tightened.

The first pipes in Russia were carried out mainly under roads and squares, i.e. where open groundworks (trenches) were associated with a number of difficulties. Since the length of the drilling channel or punctures was small, it was possible to use for laying cables, for example, asbestos cement pipes because they have sufficient mechanical strength and heat resistance in all possible temperature conditions.

As the number of cable lines (CL) increased, the need for an extended pipe route began to appear, where, for obvious reasons, the use of asbestos cement pipes was no longer possible – because these pipes do not bend, have a lot of weight and friction on the ground. Thus, for laying CL, the application of the method of horizontally directional drilling (HDD) using polyethylene cold water pipes made of low-pressure high-density polyethylene (HDPE) was tested. Such pipes are inexpensive, smooth and light, have the necessary flexibility, are easily and quickly welded together to form extended homogeneous sections.

The gradual reduction in the cost of HDD technology, as well as the widespread use of inexpensive HDPE pipes, have led to the fact that this method of cable installation is preferred even when the cable could be laid in the usual way with the help of open groundworks without much interference for the daily life of cities. As a result of this trend, the number of lines with extended pipe routes is constantly growing, and, for example, lines are already known, the route of which almost completely runs in HDPE pipes.

Unfortunately, as it turned out, HDPE pipes are designed to operate in the temperature range up to 40°C, which is less than the temperature of 90°C characteristic of the normal mode of cables with XLPE insulation, and significantly less than the temperatures that may be when short circuits occur in the cable or in the external network. Due to the insufficient heat resistance of HDPE pipes, there is a risk of their critical deformation and/or fusion with the cable outer sheath, which excludes the possibility of removing the cable from the HDPE pipe in order to repair or replace it.

The noted disadvantages of HDPE, in fact, cause underutilization of the capabilities of expensive 6-500 kV CL and high-tech modern HDD method. Therefore, recently, heat-resistant pipes ProtectorFlex made of a special polymer composition have been increasingly used to organize pipe routes. They have number of important advantages over HDPE pipes, one of which is an increased long-term permissible temperature.

Let's take a look at the consequences of the mass application of HDD technology and HDPE pipes for 6-500 kV CL with XLPE insulation.

Steady-state thermal regime of the cable line laid in pipes

In Fig.1a shown the basic design of a single-core 6-500 kV cable having a core, insulation, a copper screen requiring grounding, as well as an outer sheath (to protect the cable from water penetration). In Fig.1b schematically shown the cable laid in an air-filled polyethylene pipe placed in the ground.

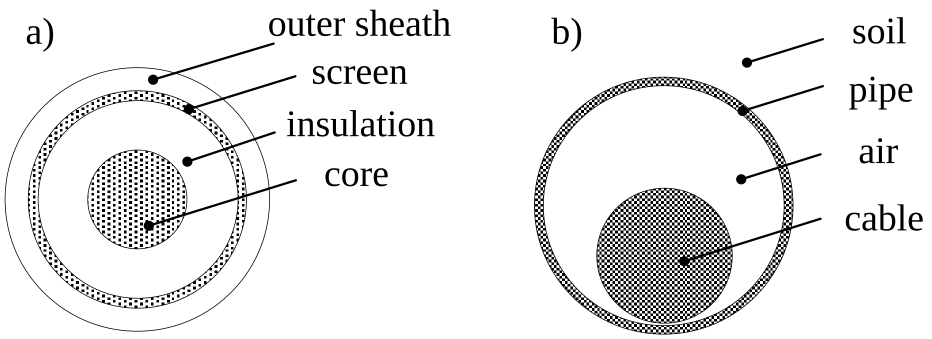

Fig.1. The construction of a single-core 6-500 kV cable:
(a) – cable with XLPE insulation; (b) – cable laid in a polyethylene pipe in the ground.

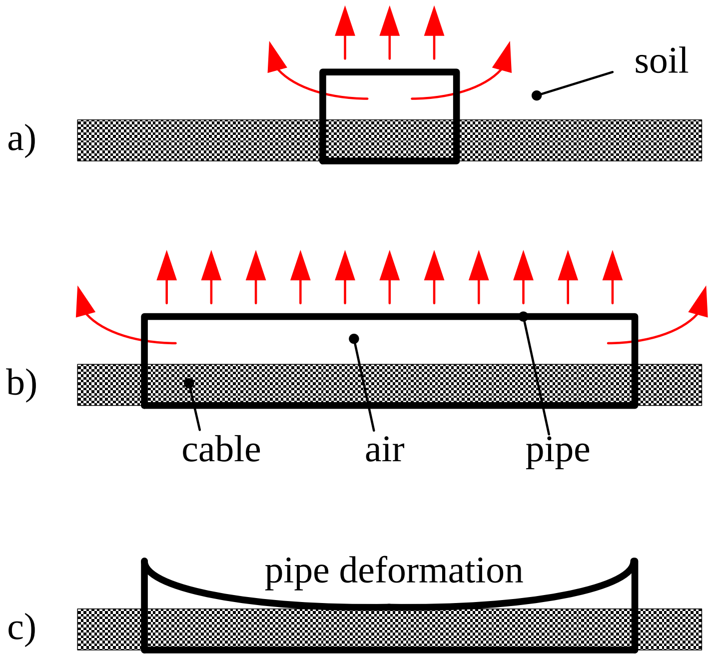

Fig.2. Cable cooling when laid in the pipe:
(a) – a short pipe section;
(b) – long pipe section;
(c) – deformation of a long pipe in its middle part.

With an increase in the lengths of the sections of the CL laid in the pipes, its cooling will gradually deteriorate, which means that the cable current capacity will decrease, which is determined based on the inadmissibility of prolonged overheating of the insulation made of XLPE over 90°C [1].

So, in Fig.2a it is shown that the cooling of the cable in a short pipe occurs not only due to the removal of heat into the ground in the radial direction, but also partially in the axial direction – along the axis of the cable. Due to this, the current capacity of the cable is reduced slightly (by 5÷10%) compared to the case when the cable would be laid in the open ground without the use of a pipe.

In Fig.2b, as the length of the pipe increases, it becomes clear that the middle section of the cable loses the ability to cool in the axial direction, i.e. it will have an increased temperature, which causes the cable capacity to decrease more noticeably (by 10÷20%).

Unfortunately, in some cases, at the design stage, an incorrect thermal calculation of the CL leads to an overestimation of the expected cable capacity compared to the real one. For this reason, cable overheating may occur during subsequent operation, especially in difficult areas [2]. In addition to the negative consequences for the insulation of the cable itself, problems may arise with the pipe.

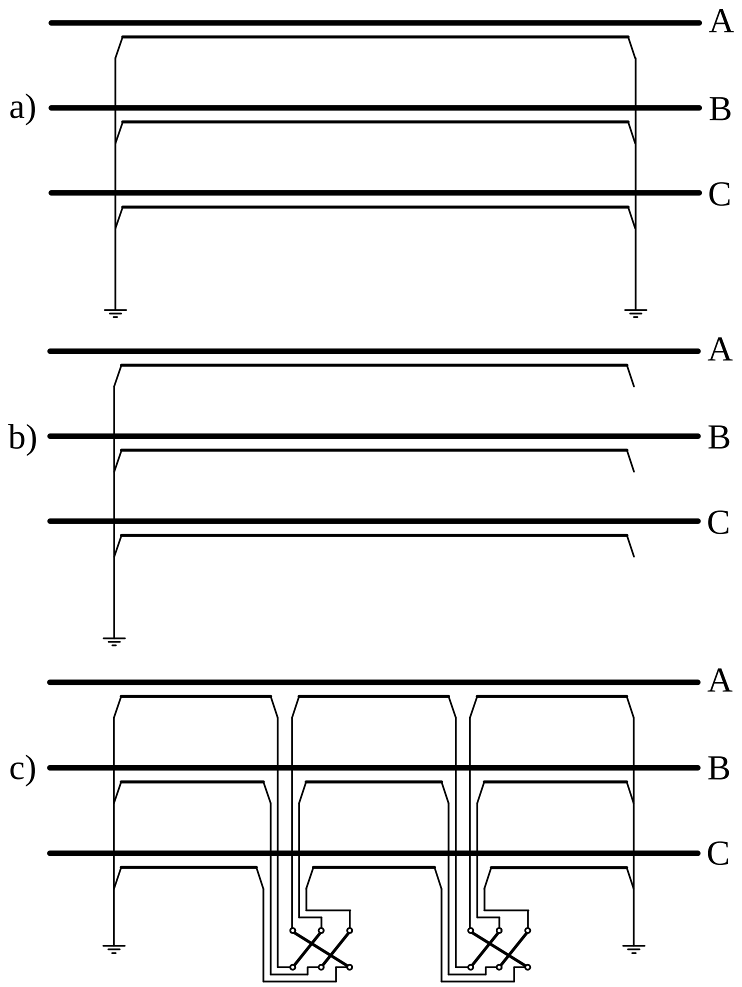

Fig.3. Basic schemes of screens bonding and grounding for single-core cables 6-500 kV:
(a) – grounding of screens on both sides;
(b) – grounding of screens on one side;
(c) – screen’s cross-bonding (transposition).

If the pipe in which the cable is laid is not sufficiently heat-resistant, then under the influence of the cable temperature it may lose its mechanical strength and deform, getting closer to the cable laid in it (Fig.2b). It is also possible that the pipe will not lose its ring stiffness, but will soften somewhat (especially the inner layer) and stick to the cable sheath. In any case, it will be impossible to remove the cable from the pipe if such a need arises.

One of the ways to reduce the insulation temperature of a 6-500 kV CL and increase its current capacity is to combat parasitic currents and power losses in cable screens induced by the operating currents of the cores. These losses exist with a simple two-side grounding of the screens (Fig.3a), but they are absent in the schemes of Fig.3b and Fig.3c [3]. Thus, for CL with long pipe sections, it is important to use:

– heat-resistant pipes;
– screen grounding schemes without power loss in the screens.

Search for damages of cable line laid in pipes

Damage to single-core cables can be divided into damage to the main insulation and damage to the outer sheath.

If we talk about the *main insulation*, then its damage almost always falls on the cable joints or terminations and is related to the quality of the couplings and their installation. Since cable couplings are arranged outside the pipe sections, the presence of pipes does not change the conditions for searching for insulation damage and its repair.

If we talk about the cable *outer sheath*, then its damage occurs much more often than that of the main insulation, and can occur anywhere along CL route, including on pipe sections. Violation of the integrity of the sheath, as a rule, is associated either with careless installation, or with external influences during operation (groundworks near the CL, subsidence of soil, etc.). For example, during installation, the cable was tightened into the pipe and at the same time its outer sheath was seriously scratched – one of the possible cases when the damage to the sheath would be in the area inside the pipe.

Regulatory documents prescribe periodic tests of the sheath of single-core 6-500 kV cables with a 10 kV DC voltage for 1 minute. In case of severe damage, the outer sheath will not withstand such tests, the place of its damage will have to be searched and repaired.

Existing methods allow you to determine the location of damage to the outer sheath of a CL laid in the open ground. However, if the damage is in the pipe section, then it will no longer be possible to find its exact location in the pipe. The fact is that the polyethylene pipe isolates the cable from the surrounding ground and the current output from the screen through the damaged sheath into the ground is possible only at the ends of the pipe. The instruments will record the presence of processes at the ends of the pipe, but it will not be possible to determine exactly where the cable sheath is damaged in the pipe.

Since there is no guarantee that there is no moisture in the pipe that can penetrate into the cable through the damaged outer sheath, the damage point must be promptly detected and restored. Alas, the only way to do this is to cut the cable at the ends of the pipe section, remove it from the pipe, find the damage point, fix it, and then put cable back into the pipe and put unplanned joints at the ends of the pipe section. However, even if you are willing to perform such a complex repair, it may not take place due to the impossibility of removing the cable from the HDPE pipe due to its deformation and/or sticking to the cable sheath.

Repair or replacement of the cable line laid in pipes

HDD technology is convenient at the stage of CL installation, but it would be nice to fully enjoy its advantages also during the subsequent operation of the line. In other words, if necessary, it should always be possible to remove the cable from the pipe.

In order to remove the cable from the pipe without hindrance, three important conditions must be met:

– the pipe must not be deformed due to the incalculable temperature conditions into which it could fall during the operation of the CL;
– the pipe should not stick together with the cable;
– the pipe should not be silted due to poor sealing of its ends.

Strictly speaking, when laying to the ground the most critical CL with single-core cables, in addition to three main pipes, one more pipe can be provided (Fig.4b), acting as a reserve, in case something happens to the cable in one of the three main pipes and it will not be removed from there. However, it is possible to imagine a situation when, for 30-40 years of operation of the CL, its repair will be required, say, twice and one reserve pipe will no longer be enough.

Obviously, it makes sense to maximize the capabilities of each of the main pipes, and use a reserve only in the most urgent cases. To do this, it is necessary to recognize the importance of fulfilling the above conditions: each pipe must be heat-resistant (mechanically strong, non-sticky); the ends of pipes must be closed.

If we talk about sealing the ends of the pipe as it is able to prevent the ingress of soil and groundwater into the pipe, then this task is not difficult to solve. The most difficult tasks are to ensure the absence of pipe annular deformation and its adhesion to the laid cable.

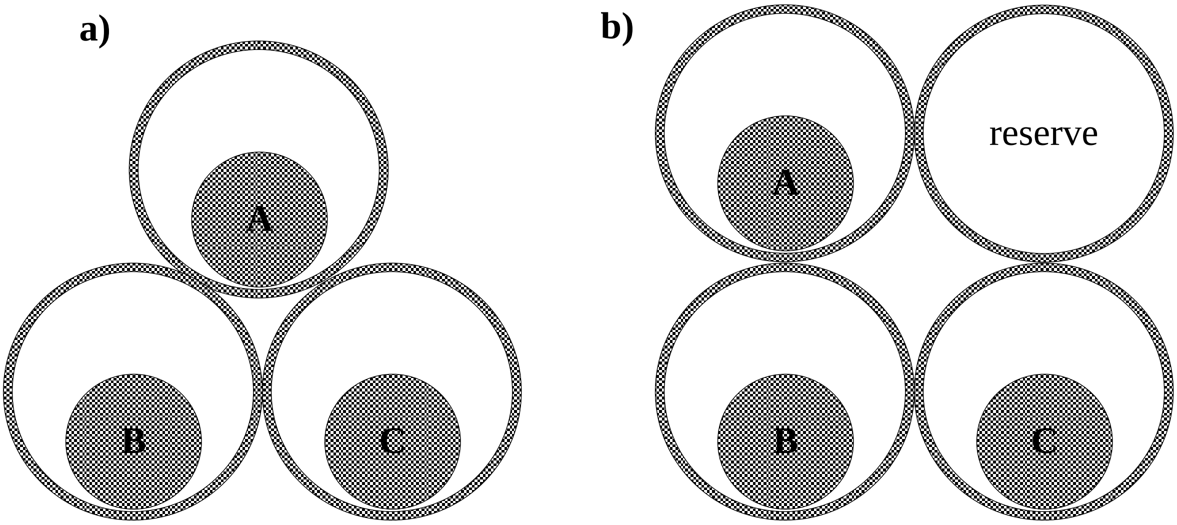

Fig.4. A 6-500 kV CL with single-core cables laid in pipes without a reserve pipe (a) and with it (b).

Disadvantages of HDPE cold water pipes when using for cables

Currently, low-pressure polyethylene (HDPE) pipes are widely used when laying CL using the HDD method. These pipes, in fact, are cold water pipes and according to GOST 18599-2001 are designed for long-term operation in the temperature range up to 40°C, and their melting point is only 132÷135°C [4]. At the same time, it is known that the temperature of a CL with single-core cables with XLPE insulation in normal mode can reach 90°C. In addition, in some cases, the line temperature may exceed 90°C, for example, this is possible during overloads. Or is it possible in cases where the actual cable current capacity turned out to be less than the values required by the consumer, for one of the reasons:

- the thermal calculation was performed incorrectly (it contains an underestimated value of the thermal resistance of the ground; the thermal resistance of the pipe and the air that fills it are not accurately taken into account; other possible errors);
- the grounding scheme of the CL screens is incorrectly selected (mounting of the scheme of Fig.3a instead of optimal schemes Fig.3b and Fig.3c).

Another case of overheating the CL above 90°C is short circuits either in the network external to the cable or in the cable itself.

If we talk about *external short circuits*, then their supply through the cable cores is an additional source of heating for both the cable itself and the pipe in which it is laid. For example, if in a mixed network containing both cable lines (CL) and overhead lines (OHL), a short circuit was on the OHL and an automatic reclosure (AR) was repeatedly started on the OHL for a short time, it is obvious that with some network circuits, the cable will flow through short-circuit currents and will be heated over 90°C and the process of cable cooling down to the initial 90°C will take from tens of minutes to several hours (the time constant of heating/cooling the cable is exactly that and is associated with the inertia of thermal processes in the ground).

If we talk about *internal short circuits*, then here the short circuit current of the network passes through the core of the cable through the place of insulation damage into the screen and further into its grounding system. At the same time, the core temperature can reach 250°C, and the screen – up to 350°C [1]. After rapid (during a short circuit) heating of the core and screen with a short circuit current to the specified temperatures, the core and screen give their heat to the cable insulation and its outer sheath, and their final temperature will depend on the heat capacity of the insulation and sheath.

According to calculations, if the temperature of the core and the screen reaches the limit values of 250 and 350°C, respectively, then such heat release in the cable is enough to evenly warm its insulation and outer sheath to 140÷160°C. The specific values of the final temperature depend on many factors, including the cross section of the core and the cable screen, the class of the rated voltage of the cable (on the volume of insulation). Heating of the insulation and the sheath occurs no later than several tens of minutes from the moment of short circuit and disconnection of the cable from the network by relay protection, but the cooling of the cable to the temperature of the surrounding ground (about 15°C) will occur slowly – up to several days (due to the inertia of the ground).

Since the melting point of the HDPE pipe is only 132÷135°C (and the softening temperature is even lower), it should be expected that the pipe will deform and/or stick to the cable sheath both during cable overloads and with short circuits external to the cable, and especially with internal damage the line itself.

Deformation of the HDPE pipe and/or its adhesion to the outer sheath will make it impossible to remove the cable from the pipe for the purpose of its repair or replacement – either the use of a single reserve pipe (if it was provided), or a long and expensive organization of a new pipe route for the damaged phase, as well as the purchase of a single-core cable of the required length will be required. By the way, ordering the cable, its manufacture and delivery to the installation site can take up to several months.

The results of some preliminary laboratory studies of HDPE pipes under the conditions of exposure to temperatures characteristic of CL with single-core cables with XLPE insulation are shown in Fig.5, 6, 7. The deformation of the pipe and its adhesion to the cable outer sheath recorded here make it impossible to extract the cable from the pipe if such a need arises, which increases the costs of the operating organization for the repair of the CL, or, in other words, leads to underutilization of all the possibilities of both HDD technology and the CL themselves.

The cable sheath is made of low-pressure polyethylene. However, unlike HDPE pipes, the sheath is not made of ordinary HDPE, but of special cable grades of polyethylene with additives and flame retardants. Therefore, the cable outer sheath has a higher softening and melting temperature, i.e. it’s the HDPE pipe that is to blame for the sticking of the cable with the pipe, and not the cable sheath.

Fig.5. Overheating of the HDPE pipe and its deformation.

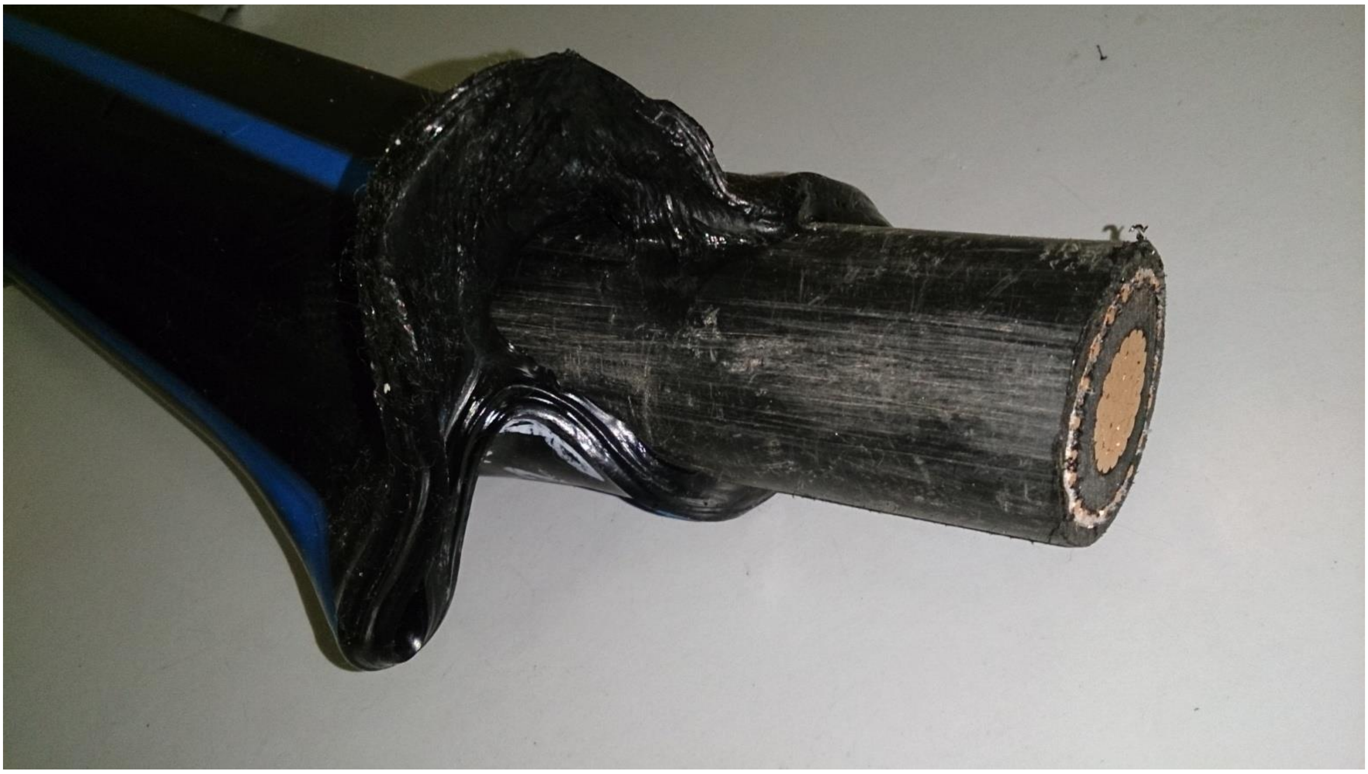

Fig.6. Deformation of the HDPE pipe and pinching of the single-core cable laid in it.

Fig.7. Adhesion of HDPE pipe to the surface of the cable outer sheath.

If, due to some exceptional circumstances, a short circuit in the CL occurs in pipe section of the route, then the temperature of the cable and pipe at the short circuit point can reach very high values of thousands of degrees, which not only any polyethylene, but even metal pipe cannot withstand. In this case, it will be impossible to ensure the integrity of the pipe and the absence of its adhesion to the cable. However, here, again, it should be noted that according to operating experience, for obvious reasons, the vast majority of damage to the main insulation of 6-500 kV cables falls on joins and terminations or on areas with cable laying in the open ground that do not have protection by trays or pipes. We also note that the protection of the cable laid in the pipe is not due to the pipe itself, but due to the fact that when the HDD is laid, the pipe is laid at a great depth (up to 3 m or even more), which excludes its damage by third-party organizations during excavation work.

Considering the above, a short circuit in the cable in the pipe section should be considered almost unlikely and not taken as a design case. The main attention should be focused on the operation of the pipe in normal mode, taking into account possible overloads and during the passage of short-circuit currents through the cores and screens, the place of which lies outside the pipe section.

Studies have shown that HDPE pipes made according to GOST 18599-2001 are not suitable for laying 6-500 kV CL with XLPE insulation, since they are designed to work at temperatures only up to 40°C.

Requirement for pipes when laying cable lines

The listed features of the extended (long) pipe sections of the cable route, as well as the properties of HDPE pipes, make us seriously think about the requirements for pipe sections and the pipes used on them.

The main specific requirement for pipes that can be used for laying CL is their heat resistance in various operating modes of the CL, which consists in the fact that the pipes should not lose ring stiffness and stick to the cables.

For 6-500 kV CL with XLPE insulation, the pipes must be heat-resistant:

- firstly, at temperatures up to 90°C that are characteristic for a long-term normal regime;
- secondly, at temperatures up to 150°C (or more) associated with overheating of the cable by short-circuit currents or with possible errors in the design of CL (incorrect thermal calculation, incorrect grounding scheme of screens, incorrect overload accounting).

In addition, the pipes must have characteristics that would allow them to be easily mounted using HDD technology:

- the pipe must be sufficiently flexible;
- the pipe must be subjected to contact welding to organize continuous pipe routes of long length.

Conclusions

HDPE pipe is a cold-water supply pipe and is designed for long-term operation in the temperature range up to 40°C, which is significantly less than the temperature values that are typical in various operating modes of 6-500 kV CL with XLPE insulation. Therefore, it is advisable to suspend the use of HDPE pipes for laying 6-500 kV CL and, instead of them, use heat-resistant pipes.

It is recommended to lay CL of rated voltage classes from 6 to 500 kV not in HDPE pipes, but in ProtectorFlex type pipes made of a polymer composition of high temperature heat resistance.

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