POLYMER PIPE AS THE MOST IMPORTANT ELEMENT OF THE 6-500 kV CABLE SYSTEM

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Previously in the magazines "CABLE-news" and "ELECTRICITY. Transmission and distribution" a number of articles were published where the problems of 6-500 kV cable lines laid in polymer pipes were considered (for example, [1]). Over the past year, design, installation, and operating organizations have become familiar with the work on pipes and have tried to form their own opinion on this matter. Also, manufacturers who began to offer various technical solutions for pipe laying of cable lines did not stay aside. The new article contains answers to emerging questions and comments on changes in the industry.

LAYING OF CABLE LINES BY HDD METHOD

One of the advantages of cross-linked polyethylene (XLPE) insulation is the absence of restrictions on the height difference along the cable line route. This property, which was deprived of cables with paper-oil insulation and oil-filled, has seriously changed the methods of cable line (CL) construction. In particular, it has become commonplace:

– the arrangement of so-called open transition points [2] between overhead and cable lines, when at the point of transition, the cable terminal couplings are placed directly on the traverse of the pylon at a high altitude, saving land that previously had to be taken away for the construction of transition point;
– laying of CL by horizontal directional drilling (HDD) with a length of more than 500 m and a cable laying depth of more than 10 m.

As can be seen, the absence of restrictions on the height difference allowed not only to raise the modern cable to a great height above the ground (overhead line pylons), but also to lower it to a great depth underground (HDD method).

If initially the laying of cables with XLPE insulation by the HDD method was used only for passing under obstacles (roads and railways, squares, water barriers), now there are more and more lines consisting entirely of HDD sections with a length of 300-500 m each. There are probably several reasons for the increased popularity of HDD:

– reduction of the number of approvals in various instances;
– reduction of the volume of earthworks and acceleration of construction.

The above-mentioned reasons for the development of HDD, first of all, serve the interests of design and installation organizations – they are interested in simplifying and speeding up CL design and construction. As for those who operate cable networks, they worry about something completely different:

– reliability and durability of cables;
– maintainability of cables or the possibility of their complete replacement.

Unfortunately, CL laid by the HDD method do not always meet the requirements of operating organizations listed above, because with HDD cables often appear in unsuitable pipes, and even at a considerable depth.

CABLE MAINTENANCE ON THE PIPE SECTION

Obviously, if we try to take into account the interests of the operating organization, and not just designers and installers, then the issues of repair or replacement of cables must be resolved. Without solving these issues, the HDD method is not a way of building the networks of the future, but a great way to bury in the ground an expensive cable (up to 0.5 million-euro per kilometer).

Repair or replacement of the cable laid by the HDD method is possible only if the polymer pipes in which the cable is placed assume multiply use, i.e. it’s possible to freely remove the cable from pipe and then tighten it back. To provide such an opportunity, it is necessary:

- use such polymer pipes that will not only lay the cable, but also retain all their strength properties for decades to come;
- securely close the ends of the pipes in order to prevent their silting.

The quality of pipes and the sealing of their ends are two key points in which the interests of installation and operating organizations radically diverge. If installers consider the pipe only as a way to quickly build a CL, then operating organizations should consider the pipe more thoroughly – as a full-fledged element of the cable system, as a reliable, long-lasting reusable cable channel.

The number of CL laid in pipes by the HDD method will only increase over the years, and operating organizations need to realize as soon as possible the importance of strict control over HDD, the materials and technologies used.

EXPERIENCE OF LARGE CITIES

One of the first operating organizations that started to restore order in the field of HDD was PJSC "Lenenergo" (St. Petersburg), which is the largest company in our country servicing cable networks of 6-110 kV of considerable length, leading in the number of CL laid by the HDD.

Here, in 2015, the decision of the technical council formulated the requirements [3] for polymer pipes for laying CL using the HDD method. These requirements are quite strict, but their goal is clear and correct – to achieve the highest quality of installation work, materials and technologies used, because only in this case PJSC "Lenenergo" will receive from installation organizations CL laid in long-lasting cable channels, providing cable repair or replacement if such a need arises.

The requirements [3] have been published and communicated to all interested parties, and there have already been cases when installation organizations, under pressure from PJSC "Lenenergo", have lost considerable time and money to alter the work performed.

Another city where HDD is widely used is, of course, Moscow. In order to get an idea about the features of cable network installations, the author met with Moscow specialists. It turned out that Moscow has a system of concrete cable collectors that could not be created in St. Petersburg due to the high level of groundwater. Partly because of this groundwater, cable lines, almost entirely laid in polymer pipes by the HDD method, apparently began to appear in St. Petersburg. In other words, a pipe is a kind of analog of a concrete collector, which means that the requirements that are imposed on pipes are requirements similar to those for collectors. Among them:

– mechanical strength;
– tightness, no water and dirt inside;
– durability (multiple cable lifetimes);
– no spread of flame and burning.

Such requirements, apparently, formed the basis of the document [3] developed by PJSC "Lenenergo". In short, it seems that St. Petersburg is thinking about the gradual creation and development of a system of underground polymer cable channels similar to Moscow concrete cable collectors.

Some experts consider the requirement of PJSC "Lenenergo" [3] to be excessive, which concerns the need to use polymer pipes with a special inner layer for HDD that does not spread fire and burning, because the cables laid in the pipes do not have an outer sheath with the appropriate properties. However, these objections are removed if we understand that we are talking about creating a system of cable channels, the reliability of which is higher than that of the cable, and the service life is 2-3 cable life cycles. Yes, at present, an ordinary cable with an ordinary outer sheath is often placed in the pipe, but it is not known what the channel is used for in the future after the dismantling of this cable that has served its time. Therefore, PJSC "Lenenergo" gives the pipe those properties that, although not paramount today, may be in demand in the near future.

PIPE DIAMETER AND ITS SDR

According to [4], the inner diameter D_{in} of the pipe ($D_{in} = D - 2e$, where D – is outer diameter, e – is pipe wall's thickness) is recommended to take at least one and a half diameter d of the cable laid in it. A more detailed rule is proposed in [1,5]:

– for short pipe sections (up to 10 m), accept "at least 1.5 diameters" ($D_{in} \geq 1.5d$);
– in other cases, take "at least 2 diameters" ($D_{in} \geq 2d$).

As for the pipe standard dimension ratio ($SDR = D/e$), which characterizes the wall thickness e, its value can be determined by the methods developed for pressure water pipes and /or gas pipelines (however, these methods are so complex and confusing that it is almost impossible to understand them even for a specialist).

If we consider laying cables in pipes using the HDD method as a convenient way to create a long-lasting underground system of cable channels similar to collectors, then it is impossible not to ask the following two questions:

– is it really necessary to choose the pipe diameter according to the recommendations [4];
– is it correct to use the SDR pipe selection methods that are valid for pressure systems with an internal pressure of several atmospheres?

I believe that it is advisable to abandon the choice of the pipe diameter D and its SDR, and to accept some standard values that are obviously sufficient for any CL. For example, this was done in Moscow, and most 110-220 kV CL are laid in the pipes with a standard diameter of $D = 225$ mm and an SDR of 17.6. This would also be nice for St. Petersburg, as it would allow to obtain a system of standard unified underground cable channels.

How to accept the standard values of the pipe diameter D and its SDR is not the most obvious question, and the experience of Moscow here is important rather than specific values, but the approach itself that deserves attention – pipes should be of the same type throughout the city (power system).

We will express a few considerations to help those who will take up the choice of pipes suitable for the role of a typical solution.

Pipe diameter selection

In my opinion, if the possibility of a HDD machine and the available budget allows, it is always better to lean towards the use of pipes of increased diameter, and there are two reasons for this:

– it is easier to tighten the cable and remove it if necessary;
– more cable current capacity.

The first consideration is obvious, but to prove the second, let's turn to Table 1, which presents calculations of the long-term current capacity of a 110 kV CL with a 1000 mm^2 copper core and a 240 mm^2 copper screen having a cross-bonding of screens (no losses in screens) and laid phase-by-phase in 3 polymer pipes. At the same time, the pipe outer diameter D and the relative thermal resistance of the ground ρ_g varied. The following were accepted: the ground temperature is 20°C, the cable laying depth is 1 m (in fact, 110 kV CL is laid deeper), the SDR of the pipe is 11.

It can be seen from Table 1 that as the pipe diameter D grows (the ratio D_{in}/d of the inner pipe diameter D_{in} to the cable diameter d increases), the CL current capacity increases. This is especially noticeable with increased resistance of the ground ρ_g, when the current capacity of the line in the pipes turns out to be even higher than with its traditional placement in the open ground in a closed triangle (the last line in table).

Table 1. The long-term current capacity of a three-phase group of single-core 110 kV 1000/240 mm^2 cables laid in pipes with a diameter of D compared to the case without pipes.

D, mm	D_{in}/d, p.u.	Relative thermal resistance of the ground ρ_g, $m \cdot K/Wt$					
		1	1.2	1.5	2	2.5	3
160	1.64	982	930	864	780	716	665
225	2.30	1000	950	887	805	742	691
315	3.22	1027	978	917	837	774	723
Directly in ground without polymer pipes		1057	980	890	782	706	648

The conclusions from Table 1 have their explanation, because as the pipe diameter D grows:

– the gap between the pipe and the cable increases, which means that the volume of air and the role of convective heat transfer from the cable to the pipe increases;
– the area of contact of the ground with the pipes increases, which means that their cooling by the ground is facilitated.

It follows from Table 1 that the use of pipes of increased diameter $D_{in}/d \approx 3$ gives an increase in the CL current capacity by 5-10% in comparison with pipes $D_{in}/d \approx 1.5$, recommended by standard [4].

Pipe SDR selection

If calculations are carried out to justify the SDR of the pipe, which will be accepted as a standard, then the methods of pressure systems mentioned in [1] will give an excessively thick pipe wall (a small $SDR = D/e$, such as 11 or 13.6). Since any of CLs are non-pressure systems, it would be more correct to use the experience of urban sewer systems, which are also made with polymer pipes, when choosing an SDR pipe for a cable.

In sewerage systems, instead of the concept of SDR, the dual concept of SN is used, which characterizes the annular stiffness number (SN) of pipes. So, urban collectors, which are strategically important objects, according to the available preliminary information, are carried out with such ring stiffness SN, which corresponds to SDR 21. Therefore, in addition to the Moscow positive experience of using SDR 17.6 pipes for the needs of laying cables, it is possible to rely on the positive experience of using SDR 21 in urban sewers. Given the above, it can be assumed that the standard SDR pipes in our country are more likely to be SDR 17,6 and 21, rather than thick-walled and expensive SDR 9, 11 and 13,6.

PIPES PRESENTED ON THE MARKET

Recently, our country has come to understand that pipes for laying cables must be durable, capable of withstanding prolonged exposure to elevated temperature and ground pressure not only during the service life of the cable, but even beyond. Thus, it became clear that cable pipes are some special pipes that differ from usual cold-water pipes made of low-pressure high-density polyethylene (HDPE), which were used until recently and according to [6] are designed to operate at temperatures no more than 40°C, significantly lower than cable lines with XLPE insulation (90-110°C).

Of course, the industry reacted promptly and issued "special cable pipes" to the market, painted red for persuasiveness and equipped with the deceiving prefix "electro". Such pipes can currently be found in both smooth-walled and corrugated versions [7], but, unfortunately, both are most often made of the same HDPE, the inadmissibility of which has been mentioned more than once (in particular in the "Lenenergo" requirements [3]). Therefore, when choosing a pipe, you should not pay attention to its color and name, but carefully study the list of materials used in its manufacture.

Another group of pipes that are now found on the market are pipes made of so-called high temperature resistance polyethylene PE-RT. As it may seem, these pipes are certainly suitable for laying CL, because they are based not on ordinary polyethylene (PE, HDPE), but on increased heat resistance. However, there are also pitfalls here, since PE-RT is a huge group of polyethylene with a long-term permissible temperature in a wide range from 60 up to 95°C. Of course, for laying CL, only PE-RT with an operating temperature of 95°C is more or less suitable. Therefore, it is not recommended to use PE-RT if there is no reliable information on its characteristics (operating temperatures).

The third group of pipes are heat-resistant ProtectorFlex pipes, which are made of a special polymer composition. Such pipes have an operating temperature of 110°C, which corresponds to both the normal mode of cables with XLPE insulation (90°C) and overload mode (105-110°C according to [4]).

Unfortunately, there is another category of pipes in the pipe market – these are recycled pipes. Their mechanical and temperature characteristics are inferior even to HDPE of the most inexpensive brand PE 80 (not to mention high-quality HDPE of the brand PE 100 and other more expensive materials). Alas, there are cases when it was the "secondary" that was used in the construction of cable lines.

Sometimes you can hear that the quality of the pipes used does not matter, because CL with XLPE insulation are selected with a large margin, and their loading in normal mode does not exceed 50% of the permissible, and the temperature of their insulation and outer sheath, respectively, is no more than 40°C. In such cases, I really want to ask: why are cables being built all over the country with expensive XLPE insulation, designed for 90-110°C, and not using less expensive types of insulation? Also, as an argument, we can recommend reading, for example, the article [2], which describes the most important role of the concept of "cable system". Its essence is that the reliability and maintainability of a CL is determined not only by the cable itself, but by all CL elements, including couplings (terminations and joints), means of screens grounding, engineering structures through which the cable is laid.

MELTING POINT AND HEAT RESISTANCE. WHAT'S THE DIFFERENCE?

When an engineer of any level is shown a heat-resistant pipe, he immediately takes out a lighter and says: "Now we will check how heat-resistant it is...". At the everyday level, his actions are understandable, but from the point of view of materials science, everything is much more complicated. The fact is that for polymer pipes there is not only the concept of melting point, but other concepts such as softening temperature (according to Vic), heat resistance, thermal stability. At first glance, these terms are very close to each other, but in fact they are not. Without understanding them, it is impossible to understand the value of heat-resistant pipes for laying 6-500 kV CL with XLPE insulation.

Melting point (softening point)

The softening temperature (according to Vic) characterizes the moment of the beginning of softening of the material. This indicator is slightly less than the melting point, because softening, in fact, is the beginning of melting.

HDPE pipes (made of PE 100 grade polyethylene) have a softening temperature of 124°C, the so-called cross-linked polyethylene (PEX) has a temperature of 126 °C, i.e. only two degrees higher.

Judging by the softening temperature, the two named materials are practically the same, and experience with a lighter would confirm this. At the same time, it is obvious that HDPE and PEX are two completely different materials, and the best confirmation of this is the highest price of PEX in comparison with simple HDPE. Here are two examples to further illustrate the cardinal differences between HDPE and PEX.

Example 1. Currently, cross-linked polyethylene is used all over the world as the main insulation of a CL, and although its softening temperature is only 126°C, but heating up to 250 and 350°C, respectively, is allowed for the cable core and screen during a short circuit by regulatory documents [4]! There is no mistake here, because the heating and then cooling mode of the cable are only short-term, and therefore the behavior of polyethylene here cannot be characterized by a softening temperature of 126°C, obtained under the condition of a constant long-term heat supply.

Example 2. Cross-linked polyethylene is not subjected to contact welding, and HDPE pipes, on the contrary, are perfectly welded (soldered) butt-to-butt, and quite quickly and reliably.

The two examples given convincingly show that two materials with very similar softening temperatures (and subsequent melting) may actually have different physical-chemical properties and different consumer qualities. In other words, experiments with a lighter cannot reveal all the specifics of the material in any way. For example, heat-resistant pipes of the Protectorflex brand produced in Russia have a softening temperature according to Vic of 131°C and according to this indicator there is no fundamental difference from HDPE (124°C) and from cross-linked polyethylene (126 °C), but the Protectorflex material, nevertheless, has special properties.

The above shows that concepts such as "softening point" and "melting point" are not informative and cannot really tell about the polymer material, especially if it is operated at temperatures up to 90-110°C [4], which is less than the melting point of 124-131°C.

In order to characterize the material, in such cases it is necessary to operate with the concept of heat resistance – this is the property of the material to long-term temperature resistance (stability) with the obligatory preservation of all physical and mechanical properties, i.e. the absence of thermal destruction. It is by heat resistance, and not at all by melting temperature, that it is customary to distinguish polymer materials.

Heat resistance (thermal stability)

The difficulty of creating heat-resistant pipes for the needs of the cable industry is that it is necessary to find a polymer composition that would provide a combination in the same material of remarkable properties inherent in both expensive cross-linked polyethylene PEX and simple HDPE. Heat-resistant pipes should have the necessary short-term resistance to overheating (like cross-linked polyethylene PEX), but at the same time they should be subjected to butt welding without problems (like HDPE).

HDPE (PE) is not a heat-resistant polymer, and cross-linked polyethylene (PEX) and a number of other materials, on the contrary, are heat-resistant.

In accordance with GOST [6], pipes made of HDPE (PE 100 grade low-pressure polyethylene) are allowed to be used only at temperatures up to 40°C. This is due solely to the properties of low-pressure polyethylene, which is not heat-resistant (thermostable) and therefore cannot ensure the preservation of all physical and mechanical properties at a temperature of more than 40°C. In accordance with GOST [8], Appendix B, the long-term strength of the HDPE material (PE 100) is limited to 40°C, and say at 80°C (this is the temperature of the cable sheath, the core of which is heated to 90°C), the long-term strength of HDPE pipes is maintained only for 10-11 months, and then a short-term destruction of the material and a rapid decrease in mechanical strength (Fig.1).

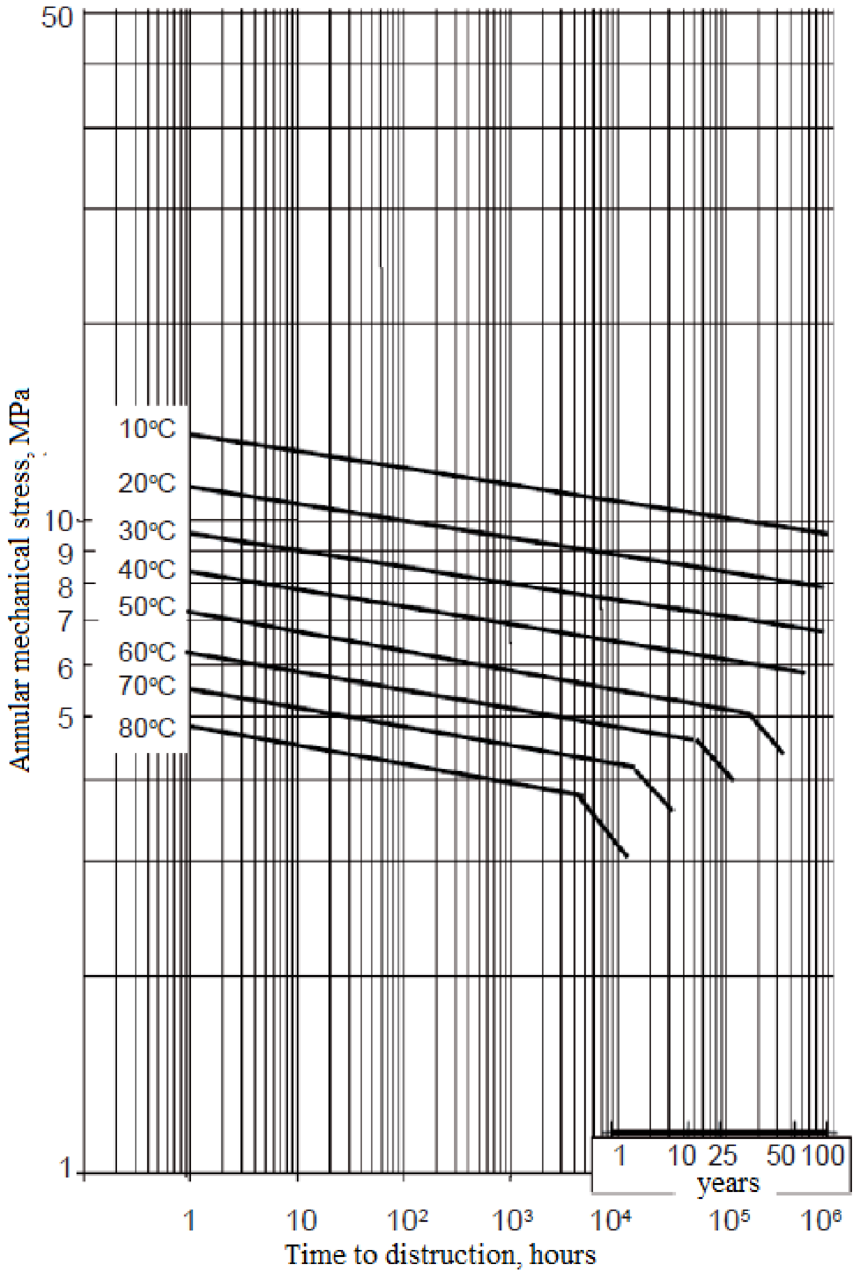

Fig.1. Reduction of mechanical strength of HDPE pipes depending on temperature and time.

The analysis of Fig.1 shows that at temperatures typical for CL with XLPE insulation, the thermal stability of HDPE pipes will remain only in the short term, and after a certain time the pipe will no longer be able to provide the possibility of repair or replacement of the cable necessary for the operating organization. This explains the refusal to use HDPE during the construction of cables and the transition to various special heat-resistant pipes.

SEALING OF PIPE ENDS

The material of the pipe used for laying the cable does not matter if the pipe ends were not securely sealed during the construction of the cable line. In other words, what kind of repair or replacement of a CL can we talk about if the pipe is silted up? Sealing the ends of the pipes is no less important than the pipe material!

Unfortunately, currently in Russia, the gap between the cable and the pipe is most often sealed with household mounting foam of the Macroflex type (for example, see Fig.5 in the article [5]). It is known that such foam is destroyed after several years of operation of the line, and then soil and water begin to flow into the pipe. Therefore, the use of mounting foam should be prohibited, and this has been done in the technical requirements of PJSC "Lenenergo" [3].

Indeed, reliable long-lasting sealing of pipe ends can be achieved only through the use of special ring seals of the type shown in Fig.2. As the bolts are tightened, the seal material is compressed and it bursts so that the gap between the cable and the pipe is filled. The plants are recommended to master the production of such seals or to offer similar technical solutions to the market as soon as possible.

Fig.2. Single-core cable with a ring seal on it.

CONCLUSIONS

1. The realities of modern cities are such that over the years the number of 6-500 kV cable lines laid in polymer pipes by the HDD method is likely to only increase.
2. Polymer pipe is an important element of the cable system, on which the possibility of future repair or replacement of the cable directly depends.
3. During the construction of CL, it is recommended to pay special attention to the material of the pipes used and the quality of sealing the ends.

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