ABOUT WAYS TO INCREASE THE CURRENT CAPACITY OF CABLES IN PIPES

Mikhail Dmitriev, PhD
info@voltplace.com

In recent years, the number of 6-500 kV cable lines (CL) with sections of the route laid in polymer pipes has been growing in Russia. The length of such sections is also gradually increasing, reaching 300÷500 m, and now it is already possible to meet lines where, in total, more than half of the route is located in pipes. Consequently, the issues of the pipe choice, its impact on the reliability and efficiency of CL are of particular relevance.

Keywords: cable line, cross-linked polyethylene, polymer pipe, cable laying in pipe, current capacity, thermal resistance.

Introduction

The capabilities of the horizontal directional drilling (HDD) method are constantly increasing and already make it possible to equip pipe sections in the ground with a length of not only tens, as originally required, but even hundreds of meters. For large cities, the development of HDD and the increased complexity of laying cables in the traditional way (in trenches) led to the expected result: now the placement of cables in pipes has become used not only locally at intersections with roads and communications, but also as a full-fledged way of building lines.

The growth of the lengths of the sections of the route laid in pipes, as it turned out, occurs not only in the HDD segment, but also in the segment of conventional trench laying. The fact is that pipes began to be perceived as an inexpensive alternative to reinforced concrete trays along the entire route of the line, as well as an opportunity for construction in several stages, performed at intervals of several months or even years.

For example, it is difficult and expensive to prepare a trench and maintain it in proper condition for a long time, waiting for the purchase and delivery of cable to the facility. In situations of limited funding or other reasons that do not allow immediately after the preparation of the trench to start laying the cable promptly, the use of pipes will allow you to get out of the situation. At the 1st stage, a trench is prepared in the ground, and pipes with installed plugs are laid on its bottom, the trench is filled in. At the 2nd stage, after paying for the 1st, purchasing and delivering the cable to the facility, only the ends of the pipes are dug out, the plugs are removed, the cable is stretched, the couplings are mounted, the line is put into operation.

The increased role of pipes poses a whole range of tasks for power engineers, including the development of requirements for polymer pipes for laying CL and methods of pipe mechanical calculation [1, 2, etc.]. Issues of thermal calculation of CL in pipes are also important:

– the influence of the thermal resistance of the pipe wall on the cable current capacity;
– cable current capacity correction factor for laying in pipes instead of ground.

Thermal calculation of the cable in the pipe

Figure 1 schematically shows a cable of external diameter d laid in the ground in a polymer pipe having an external diameter D and a wall thickness e. It can be either a three-core cable or a single-core cable (then a three-phase line has three such pipes at once with a single-core cable in each of them).

For example, if we are talking about single-core cables with cross-linked polyethylene insulation (XLPE), then the main sources of heat generation in the cable are power losses P_c in the core and P_s in the metallic screen. The specified heat is removed from the cable into the ground, for which it must overcome a chain of several thermal resistances R (Figure 2). It can be seen that on the way of heat are: cable insulation (ins), cable sheath (sh), air in the pipe (a), polymer pipe (p), ground (g).

By setting the ground temperature equal to, say, $T_g = 20°\text{C}$, using the thermal scheme Figure 2, it is possible to determine the losses in the core P_c and losses in the screen P_s, at which the temperature of the cable core will reach the level $T_c = 20°\text{C}$, that is considered as the maximum permissible in normal operation for XLPE insulation. Next, the value of the core current of the cable I_C is determined, corresponding to the losses P_c and P_s, and this value is called the cable current capacity (the long-term permissible current). The specified calculation method is reflected in IEC [3].

In the diagram Figure 2, the values of thermal resistances depend on the geometric characteristics of the system under consideration, i.e. on the external and internal diameters of insulation, outer sheath, pipe. Also, the thermal resistances R depend on the properties of materials – their relative thermal resistances ρ. The values of ρ for the cable elements and for the air are known parameters, whereas the values of ρ for the pipe and the soil in each case should be specified.

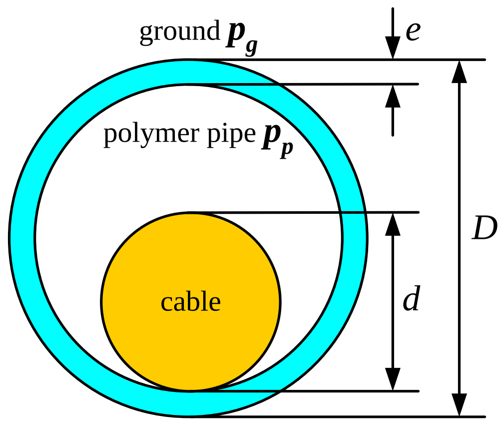

Fig.1. A cable located in a polymer pipe.

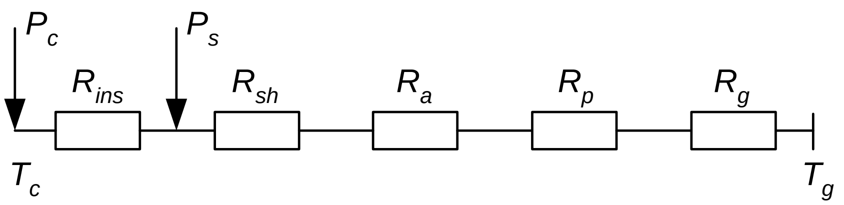

Fig.2. Thermal replacement scheme of the cable line in the pipe.

Figure 3 shows, as an example, calculations of the current capacity of a three-phase 110 kV CL made by single-core XLPE cables having cross-sections of 1000 mm^2 copper core and 240 mm^2 copper screen. We assume that there are no power losses in the screens, that is, $P_s = 0$ (the cross-bonding of the screens or their one-end grounding is made), and the three phases of the CL are laid in a closed triangle.

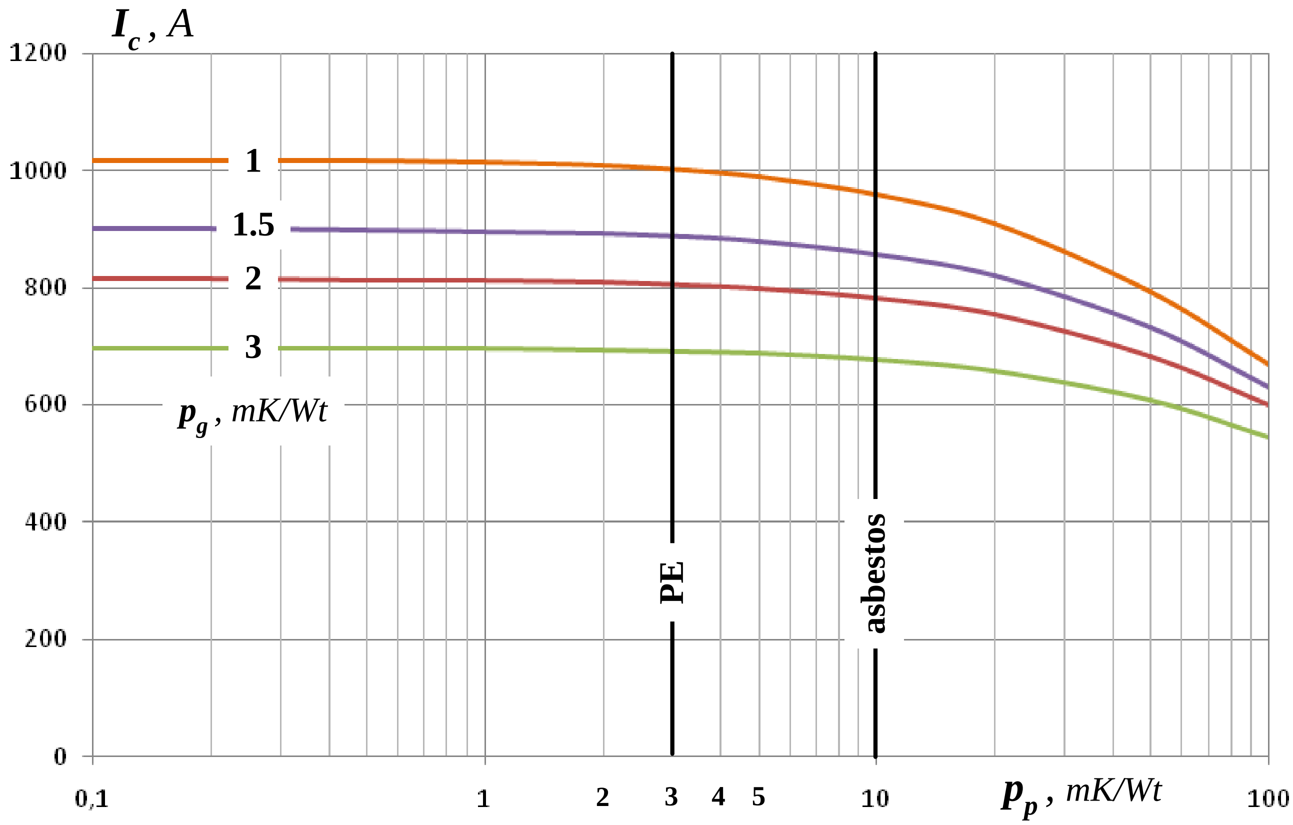

Fig.3. The current capacity of the 110 kV CL, depending on the thermal resistance of the pipe (p) and the ground (g).

We believe that each cable of the three phases of the 110 kV CL is laid in a pipe with typical parameters: outer diameter $D = 225$ mm, annular stiffness number SN 64 kN/m^2. With an elastic modulus of 950 MPa, according to Table 1 of [2], we have the ratio $D/e = 11.7$ and the wall thickness of such a pipe is equal $e = 225/11.7 = 19.2$ mm.

In the calculations of Figure 3, the following varies:

– the relative thermal resistance of the soil ρ_g in the range 1÷3 $(m \cdot K)/Wt$;

– the relative thermal resistance of the pipe ρ_p in the range 0.1÷100 $(m \cdot K)/Wt$.

According to the graph in Figure 3, for example, in the case of laying in the ground $\rho_g = 1\ (m \cdot K)/Wt$ of polymer pipes having $\rho_p = 3\ (m \cdot K)/Wt$, the current capacity is $I_c = 1000$ A.

Relative thermal resistance of the pipe wall

The dependencies in Figure 3 clearly show that in order to increase the cable current capacity I_c, one should try to provide $\rho_g \to 0$ and/or $\rho_p \to 0$. So, in particular, the transition from asbestos pipes $\rho_p = 10$ to polymer pipes made of low-pressure polyethylene (HDPE) and having a lower relative thermal resistance of the wall $\rho_p = 3$ led to an increase in the cable current capacity by 2÷4%.

At present, it has been realized that HDPE cannot be used in the construction of cable lines with XLPE insulation, and special heat-stability non-flammable polymer cable pipes have come to replace HDPE [1]. Manufacturers of such pipes, as one of the additional arguments in favor of their products, report that their pipes have a relative thermal resistance of the wall $\rho_p \leq 3$, i.e. they increase the cable current capacity in comparison with cases of HDPE and asbestos.

In fact, as follows from the thermal calculation of Figure 3, in the range $\rho_p \leq 3$, the relative thermal resistance has practically no effect on the cable current capacity I_c. This is because in the thermal scheme in Figure 2, at $\rho_p \leq 3$, the value of the thermal resistance of the pipe wall R_p turns out to be negligibly small against the background of other thermal resistances that remain unchanged.

I would like to draw attention to the fact that according to GOST [4] and other documents, when determining the relative thermal resistance, the temperature at which measurements are carried out should be indicated. So, for 6-500 kV CL with XLPE insulation, the relative thermal resistance ρ_p is interesting only at operating temperatures of 60÷90°C. Studies show that at such temperatures it is difficult for polymer pipes to reach the level of $\rho_p \leq 2 \div 3$, and for this reason some manufacturers are beginning to cheat, declaring, for example, an atypical value of $\rho_p = 1\ (m \cdot K)/Wt$, but hiding the value of the corresponding temperature, without specifying it anywhere.

Despite the absence of any need to fight for $\rho_p \to 0$ and sufficiency of $\rho_p = 2 \div 3$, there are manufacturers who continue this useless race, distracting the attention of power engineers from the really problematic issues of laying cables in pipes, among which, for example:

- the inadmissibility of using pipes that have HDPE in their composition;
- the need to create a methodology that allows in the field conditions at the facility to determine whether conventional HDPE pipes painted in red are not supplied;
- the inadmissibility of laying high-voltage power cables 6-500 kV in pipes conforming to IEC 61386-2014 "Pipe systems for laying cables" (this IEC has a scope extending exclusively to low-voltage networks up to 1 kV).

Correction factor for laying in pipes

According to the catalogues of cable factories, when laying a 6-500 kV cable in a pipe, the current capacity is reduced by 10% relative to the case of laying directly in the ground. Thus, when designing cables in pipes, designers are recommended to use a correction factor of 0.9. Unfortunately, calculations show that this value is so averaged that its use cannot be recommended in any way.

In the article [5], after performing a series of calculations on the example of a 110 kV 1000/240 mm^2 cable, it was revealed that replacing the traditional laying in the open ground with a pipe under certain conditions not only doesn't reduce the current capacity of the CL, but even on the contrary can cause its increase up to 5÷15%. The effect of an increase in the current capasity is due to the fact that with large pipe diameters, they receive a significant contact area with the ground and are well cooled. In other words, in the thermal circuit in Figure 2, the appearance of pipes leads to the need to take into account the resistances R_a and R_p, but sometimes to a much greater extent it contributes to a decrease in R_g, which ultimately causes a decrease total thermal resistance of the circuit, improved cooling of the cable cores, an increase in the current capacity.

The increase in the cable current capacity is especially noticeable, when choosing the outer diameter of the pipes, they depart from the traditional rule $D/d \geq 1.5$ described in [2] (Figure 1), using the rule $D/d \geq 2 \div 3$ instead.

Conclusions

1. Laying CL in polymer pipes can not only reduce, but also increase the cable current capacity. In general, the use of a correction factor of 0.9 for laying in pipes is incorrect.
2. The use of polymer pipes with a relative thermal resistance of less than 2÷3 $(m \cdot K)/Wt$ does not change the CL current capacity.
3. The appearance of pipes with relative thermal resistances 0.1÷1 $(m \cdot K)/Wt$ in cable networks has nothing to do with power grid real needs.
4. To increase the current capacity of CL laid in a polymer pipe, there are currently only two main ways: it is either to use pipes of increased diameter, or to provide for controlled filling of pipes with special liquid or water (without soil particles, since they can cause silting of the cable).

References

1. Dmitriev M.V. "Polymer pipe as the most important element of a 6-500 kV cable system" // ELECTRIC POWER: Transmission and distribution, 2015, No. 6(33). pp. 78-83.
2. Dmitriev M.V. "Mechanical calculation of polymer pipes" // ELECTRIC POWER. Transmission and Distribution, 2016, No. 3(36). pp. 70-75.
3. IEC 60287-1-1-2009 "Electrical cables. Calculation of the rated current capacity".
4. GOST 23630.2-79 "Plastics. Method for determining thermal conductivity".
5. Dmitriev M.V. "Cable lines laid in polymer pipes 6-500 kV. Thermal calculation" // News of electrical engineering, 2015, No. 5(95). pp. 32-34.