SELECTION OF LOAD PARAMETERS OF 110-500 kV CABLE LINES

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If we turn to the existing networks, there are both overloaded and underloaded cable lines, but the latter are much more common. In conditions of saving money, the incomplete use of line current-carrying capacity looks wasteful and requires clarification.

Keywords: cable line, single-core cable, cross-linked polyethylene (XLPE), cable screen, screens grounding, screens cross-bonding, thermal calculation, current-carrying capacity.

1. INTRODUCTION

When designing 6-500 kV cable lines (CL), single-core cables with XLPE insulation are preferably used. The current-carrying capacity (long-term permissible current) of such lines depends on the cross-section of the core and the cable screen, on the number of parallel circuits and the position of the phases relative to each other, on the properties of the ground and the grounding scheme of the screens. All of these factors need to be taken into account at the CL design stage, since otherwise there is a possibility of dangerous overheating of the XLPE insulation of the CL beyond the permissible temperature of 90°C or, on the contrary, underutilization of CL power transmission capabilities.

The alternating current of industrial frequency passing through the core of the cable heats the core due to the loss of active power, and it gives heat to the XLPE insulation. Also, in single-core cables, another important source of XLPE insulation heating is power losses in metallic (copper or aluminum) screens grounded at the ends of the CL.

When designing a CL, it is important to check the absence of overheating of the core and XLPE insulation above the permissible temperature. To do this, the thermal calculation of the CL is performed using either IEC 60287 or computer programs. However, most often designers use catalogs of cable factories, where the results of such thermal calculations are already given in tabular form for different lines, their parameters and laying conditions. So, there are current-carrying capacity $I_{CL.CAP}$ in catalogs, at which the temperature of the cable core does not exceed 90°C. Insulation overheating over 90°C is absent when the real load current I_{CL} of the CL does exceed $I_{CL.CAP}$, i.e. the inequality $I_{CL.CAP} > I_{CL}$ is fulfilled.

To select specific parameters of the CL and ensure $I_{CL.CAP} > I_{CL}$, you must have the following initial data.

1. Calculations of the CL load currents I_{CL} with indication of the operation modes in which they are obtained.
2. Cable factory catalogs having tables with current-carrying capacity $I_{CL.CAP}$ for CL cables of different core cross-sections.

Let's consider the methods of obtaining currents I_{CL} and $I_{CL.CAP}$, as well as possible reasons why the CLs selected by the designers based on the condition $I_{CL.CAP} > I_{CL}$ are underloaded in normal operation mode by so much that their XLPE insulation instead of 90°C temperature, in fact, remains "cold". This state of affairs cannot be considered normal, because, for example, the cost of each kilometer of the 110 kV cable line sometimes reaches 1 million euro, and there is no point in investing such funds in an underused line.

2. OPERATION MODES AND CABLE LINE LOAD CURRENTS (I_{CL})

The calculation of the load current I_{CL} of the CL depends on the network scheme. The easiest way is when the CL operates in a block with a transformer or overhead line (OHL) – then the operating current of the CL is inextricably linked to the current of the OHL wires or the known transformer power (Fig.1).

The situation is more complicated in those networks that do not have a simple radial structure, but have a large number of nodes and branches connected to each other and forming rings (Fig.2) – without software here it is impossible to make calculations of various normal, repair or post-accident operation modes. These calculations have to be performed not only in the actual network scheme with known loads in its nodes, but also for the future, taking into account the development of the network and the growth of loads.

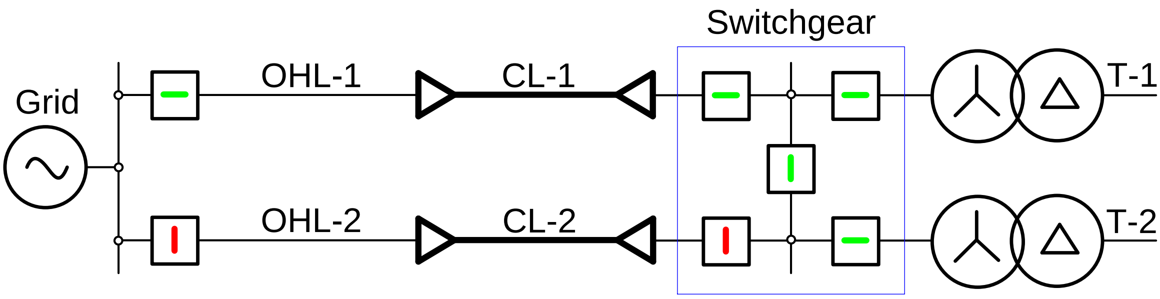

Fig.1. A simple radial network with power supply of a transformer substation through OHL/CL.

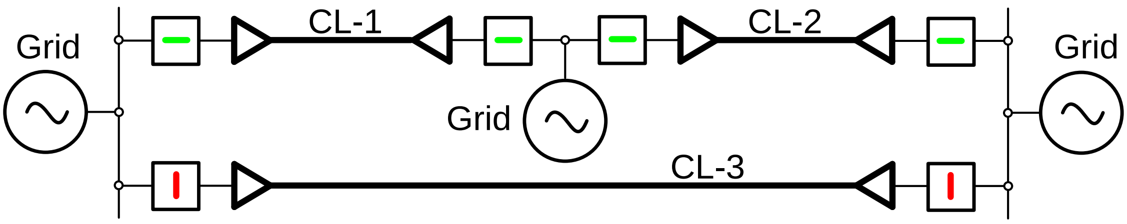

Fig.2. A complex looped multi-node network requiring computer calculation of operation modes.

Calculations by the overhead line current

If the CL is a continuation of the OHL (diagram Fig.1), then their current-carrying capacity should be coordinated with each other. In other words, the CL core current-carrying capacity must correspond to that for the OHL wires.

Current-carrying capacity for OHL wires is indicated, for example, in the appendices to the national standard STO 56947007-29.240.55.143-2013 "Methodology for calculating maximum current loads under conditions of maintaining the mechanical strength of wires and permissible dimensions of overhead lines", which is posted on the JSC "FSK EES" site. According to this document, the current-carrying capacity of the wires depends on a number of the factors, in particular, on the ambient temperature and the presence of solar radiation (its presence heats the phase wires). The values of these capacity currents are indicated in the appendix to the STO for three air temperatures: -20°C, 0°C, +20°C.

Since the CL should not limit the possibilities of OHL wires, when choosing the cable core cross-section, it is necessary to focus on the maximum current capacity of the OHL wires – it will be in cold and cloudy weather (without solar radiation), for example at -20°C. It is for the currents of the OHL wires, determined at an ambient air temperature of -20°C, it is desirable to choose the cross-section of the CL core and its other parameters.

Unfortunately, the CL designers more often determines the CL core current capacity at a temperature of +15 or +20°C, and not at all at a temperature of -20°C. Partly due to the fact that in the catalogs of cable factories there is no data on current capacities $I_{CL.CAP}$ at negative temperatures (for example, in [1] there are no temperatures below +10°C). All this leads to an underestimation of cable cooling and the choice of an overestimated core cross-section in comparison with the one that would be sufficient to pass the real load current I_{CL}.

According to the author's estimates, the current-carrying capacity of a CL at -20°C air temperature can be from 5% to 25% higher than at +20°C, and even when the CL is laid in the ground and have no direct contact with air.

Calculations by transformer power

If the CL operates in a block with a power transformer (T), then its current-carrying capacity must correspond to the rated power of the transformer.

At a known rated voltage U_r, the phase current of the transformer in normal operation mode depends not only on its rated power S_r, but also on the coefficient K_T of its load:

$$I_T = K_T \cdot \frac{S_r}{\sqrt{3} \cdot U_r}$$

As a rule, substation with two transformers (Fig.1) are designed so that the load factor of each of the transformers is $K_T = 0.7$. This makes it possible not to disconnect consumers even when one of the transformers needs to be taken out for repair, because the second one is able to work with a load of 1.4 for a certain time, i.e., with an overload of 40%.

Similar considerations can be used when choosing the load current of each circuit of a two-circuit CL that feeds a substation with two transformers. Since in the event of a cable fault, the repair of the CL can take a considerable time, therefore each of the CL circuits must be able to withstand the passage of current from two transformers at once for a long time. For example, in Fig.1, the power of transformers T-1 and T-2 goes through the CL-1 circuit, while the CL-2 circuit is under repair. Thus, each of the two CL circuits must be designed for load current:

$$I_{CL} = 2I_T = 2K_T \cdot \frac{S_r}{\sqrt{3} \cdot U_r}$$

In the catalogs of cable factories, when determining the CL current-carrying capacity $I_{CL.CAP}$, there is a correction factor K_{CIR} for the number of parallel circuits. For example, in the catalog [1] for a double-circuit CL with a distance between the circuits of 0.4 m, it is $K_{CIR} = 0.85$, i.e., the current-carrying capacity of each of the two circuits is 15% less than it would be for a single-circuit CL. To compensate for this decrease in current, it is usually necessary to use cables with an increased core cross-section.

At the same time, for the diagram Fig.1, when choosing the CL core cross-section, the K_{CIR} coefficient should not be used. Although the CL is double-circuit, the calculated operation mode is recognized, in which there is only 1 circuit but carrying the double load. The refusal to use $K_{CIR} = 0.85$ means that it is quite enough to have a CL with a small core cross-section to pass the load current I_{CL}, and it is cheaper to build this kind of CL

Calculations in the general case

The calculation of the CL load current I_{CL} is relatively simple if it is carried out by the current of the OHL wires or by the rated power of transformers. However, in the schemes of the form Fig.2, it is necessary to resort to calculations of various operation modes of network performed in specialized software. So, Fig.2 shows the mode when CL-3 is under repair, and because of this, CL-1 and CL-2 are loaded more than in normal operation mode, but it is difficult to say exactly how much without using a computer.

There are operation modes of summer and winter time, of minimum and maximum. The minimum modes are interesting from the point of view of voltage levels in the network nodes and ensuring a balance of reactive power – these issues are not related to the choice of the CL cross-section. When choosing a CL, it is the maximum modes that are important.

The currents in the CL corresponding to the summer and winter maximum should be the basis for choosing a CL. In summer, usually the network load power is less, but the cable cooling conditions are worse. Therefore, it is impossible to say in advance which of these two maximum modes (summer or winter) will be decisive for choosing the cross-section of the core, and all calculations must be carried out twice.

In addition, currents in the winter and summer maximum modes are considered not only in the network normal operation mode, but also in various post-accident and repair operation modes. Therefore, it is very important that if not all circuits of a multi-circuits CL were in operation in these modes, then this was taken into account when choosing CL cores by correct value of coefficient K_{CIR} (correction factor taking into account circuits number).

It should also be noted that the load currents in the CL are likely to increase over the years due to an increase in the network load power. Therefore, the calculation of operation modes should be made for the future. Unfortunately, this is a very unpleasant place when choosing cables, because no one can guarantee whether the loads will really increase and, moreover, no one can claim to know how much such an increase will occur.

To believe or not the plans for the development of the power system and increasing of network loads is a question that every grid company must solve for itself, but I want to ask the obvious question – is it worth buying and laying expensive cables with an increased core cross-section if it will be possible to use the current-carrying capacity of these cables not earlier than after 10-30 years, or maybe never at all?

3. CABLE LINE CURRENT-CARRYING CAPACITY ($I_{CL.CAP}$)

The CL current-carrying capacity $I_{CL.CAP}$ is determined during the so-called "thermal calculation", taking into account the main influencing factors affecting the release of heat in the cable and its removal into the surrounding space. For cables with XLPE insulation, a current at which the temperature of the insulation adjacent to the core does not exceed 90°C is considered $I_{CL.CAP}$.

Heat dissipation

In a single-core cable, power losses occur in the core (P_C) and screen (P_S) and depends on the following factors described in [3]:

- core cross-section and its material (these factors influence on P_C value);
- screen cross-section and its material (these factors influence on P_S value);
- screens bonding/grounding scheme (influences on P_S);
- mutual arrangement of three CL phases (influences on P_S).

Of the four factors listed, the first one affects losses P_C in the core, and the other three affect losses P_S in the screens.

Cooling

The cooling of the cable occurs due to the removal of heat from the core and the screen through the insulation and outer sheath into the environment (more often this is the ground). It depends on the following factors specified in IEC 60287 or, for example, in [2]:

- thermal resistance of the ground (of the soil);
- laying depth of the cables;
- the temperature of the ground and the air above the ground surface;
- mutual arrangement of CL phases;
- the presence of adjacent CL circuits or hot-water pipes;
- the presence of the CL sections laid in pipes.

Heat balance

Understanding the complexity of the calculation according to IEC 60287 or in special software, the thermal calculation of the CL is often performed in a simplified manner using the data provided in the catalogs of cable manufactories.

Having carried out a series of thermal calculations for different core cross-sections, cable manufacturers compile catalogs (see [1]), where the dependence of the cable current-carrying capacity on the core cross-section is given in tabular form, correct under certain basic conditions (laying depth, ambient temperature and ground resistance, etc.). In cases where the operating conditions of the CL differ from the basic ones, it is proposed to use a system of correction coefficients, the values of which are also available in catalogs.

As a rule, one of the basic conditions is the absence of screen power losses ($P_S = 0$), which is characteristic of the rejection of simple grounding of screens on both sides and the use of one-side screens grounding (for "short" cables) or screens cross-bonding (for "long" cables) [3]. For this case, we will call the current capacity "ideal" and denote $I_{CL.CAP.ID}$.

Actual value of CL current-carrying capacity can be estimated based on the "ideal" capacity $I_{CL.CAP.ID}$ obtained in the case of lossless screens, by using correction coefficients:

$$I_{CL.CAP} = K_{SCR} \cdot K_{CIR} \cdot K_{DEP} \cdot K_{TER} \cdot K_{PIP} \cdot I_{CL.CAP.ID} \tag{1}$$

where K_{SCR} – correction for the power losses in the screens;
K_{CIR} – correction for the number of the CL circuits;
K_{DEP} – correction for the depth of the CL in the ground;
K_{TER} – correction for the specific thermal resistance of the ground (soil);
K_{PIP} – correction for laying cables in pipes.

Formula (1) does not include all coefficients, but only those that are required to perform the calculation examples given at the end of the article. For instance, in (1) there is no correction factor for the environment temperature (soil, air). There is also no correction for the distance between the CL phases if these phases are located at a distance from each other greater than or less than the base value at which the current $I_{PLC.ID}$ is obtained. A more complete list of coefficients is available in [1].

Of the entire system of correction coefficients, only K_{SCR} has an analytical expression, and the others can be obtained only as a result of a series of thermal calculations carried out using software.

The screens factor K_{SCR} depends on the ratio of losses in the screen and the core P_S/P_C and can be found according to the book [3] as

$$K_{SCR} = \frac{1}{\sqrt{1 + P_S/P_C}} \tag{2}$$

The ratio P_S/P_C is easy to find by the formulas from the book [3] or the dependencies given there. If there are no losses in the screens, we have $P_S/P_C = 0$ and $K_{SCR} = 1$.

4. SELECTION OF CABLE LINE PARAMETERS THAT PROVIDE $I_{CL.CAP} > I_{CL}$

The core and the screen cross-sections, and the screens bonding/grounding scheme, and the mutual arrangement of the CL three phases affect the XLPE insulation temperature. Simultaneous consideration of all these factors is difficult, and therefore it would be convenient to divide the cable selection into separate stages. The choice of the core cross-section, which is the "main" element of the cable, is actually carried out at the last stage.

The stage 1 – Screen cross-section selection

The method of selecting the cable screen cross-section based on data on short-circuit currents and their flow time is described in [4]. Depending on the method of network neutral grounding, when choosing the screen cross-section, different types of insulation faults will be calculated – single-phase-to-ground or double-phase-to-ground short-circuits.

The stage 2 – Choosing the relative position of single-core cables

According to the author, the laying of phase cables is preferable in a closed triangle, since this ensures:

- minimum screen currents and power losses when the CL has two-sides grounding;
- minimum screen induced voltages when the CL has screens one-side grounding or their cross-bonding;
- the safety of repair work on multi-circuit CL (due to reduced induced voltages);
- symmetry of the CL longitudinal active and inductive impedances in phases;
- increase of the culture of CL construction.

However, in addition to the closed triangle, other ways of mutual arrangement are also possible, which, according to the author, should mainly be forced. For instance, we are talking about laying of CL three phases in three separate polymer pipes put to the ground by horizontal directional drilling (HDD), when even if desired, it will no longer be possible to provide a closed triangle of phase cables. Thus, the choice of the position of the CL phases relative to each other (triangle or row) is determined in advance by the features of the CL route and the laying conditions:

- if the CL is in the open trench, then for the reasons mentioned above, it is always better to lay phase cables in a closed triangle;
- if the CL is in the pipes (HDD or other circumstances), then it is better to place them in a triangle so that the phase cables are also a triangle, although, alas, not closed.

The stage 3 – Selection of the screens bonding/grounding scheme

In [3] it was shown that for any CL with single-core cables, the use of simple screens two-side grounding is not recommended, since this leads to the need to pay for parasitic power losses in screens (up to 10 thousand euro annually for entire CL) and reduces the CL current-carrying capacity by the value from 5% ($K_{SCR} = 0.95$) and up to 50% ($K_{SCR} = 0.5$) that is too much to agree to have screens two-sides grounding. Therefore, when choosing a bonding/grounding scheme, in fact, it is necessary to determine only which way to combat screens currents and losses – either by one-side screens grounding (for "short" lines), or by the screens cross-bonding with a certain number of cycles (for "long" lines). Whichever of the methods is adopted to combat screens currents/losses, anyway we have $K_{SCR} = 1.0$ that have to be taking into account when using the formula (1).

The stage 4 – Core cross-section selection

Having selected the screen cross-section, the relative location of the phase cables and the screen bonding/grounding scheme, as well as knowing the conditions under which the CL load current I_{CL} is obtained, you can proceed to thermal calculation and search for the core cross-section at which the temperature of the XLPE insulation will be less than 90°C, i.e. the CL current-carrying capacity $I_{CL.CAP}$ meets the condition $I_{CL.CAP} > I_{CL}$.

5. EXAMPLE FOR CABLE LINE OF 110 kV CLASS

As an example, Table 1 shows the current-carrying capacity $I_{CL.CAP.ID}$ for a 110 kV CL made of single-core cables with a copper core/screen and XLPE insulation. The data are borrowed from the ABB catalog [1] and valid in the "ideal case" when there are no screens currents I_S and losses P_S (one-side screens grounding or their cross-bonding is applied). The basic conditions for laying three cables in the ground were as follows: depth $h_G = 1$ m, specific thermal resistance of the soil $\rho_G = 1\ K \cdot m/Wt$, temperature 20°C, one circuit.

Table.1. Current capacity $I_{CL.CAP.ID}$ (A) by [1] for a three-phase group of 110 kV single-core cables laid in the ground with a copper core in the case when there are no screen currents and losses.

F_C, мм^2	$I_{CL.CAP.ID}$, A	
	Closed triangle	In a row*)
300	600	625
400	680	715
500	770	815
630	**865**	925
800	960	1035
1000	**1050**	1140
1200	1215	1295
1400	1300	1390
1600	1375	1475
2000	1490	1610

Note: The “in light” distance between adjacent phases was assumed to be 0.07 m (70 mm).

Using Table 1 and other data [1], we select a 110 kV double-circuit CL, through which the substation will be supplied with two 110/10 kV transformers with a capacity of 80 MVA each (diagram Fig.1).

Based on the calculation of the short-circuit currents of the network, the cross-section of the screens is assumed to be 240 mm^2 (method [4]), the cable phases are supposed to be laid in a closed triangle in the trench in ground with a thermal resistance $\rho_G = 2\ K \cdot m/Wt$ ($K_{TER} = 0.74$ by [1]) at a depth of $h_G = 1.5$ m ($K_{DEP} = 0.95$ by [1]). The grounding scheme of the screens is without screen currents and power losses ($K_{SCR} = 1$ according to the (2)).

With a transformer load factor $K_T = 0.7$, the phase current of the power transformer on the 110 kV side will be:

$$I_T = K_T \cdot S_r/\left(\sqrt{3} \cdot U_r\right) = 0.7 \cdot (80 \cdot 10^6)/\left(\sqrt{3} \cdot 110 \cdot 10^3\right) = 294 \text{ A}$$

Since one of the two circuits of the CL can be under repair for a long time, the circuit remaining in operation must be designed for the passage of current from two transformers at once, i.e., the calculated load current for each circuit will be

$$I_{CL} = 2I_T = 588 \text{ A}$$

The load $I_{CL} = 588$ A is obtained under the assumption that there is only one circuit of CL in operation, i.e., when conducting CL thermal calculation and cable core selection, correction coefficients for the number of circuits do not need to be entered, i.e., $K_{CIR} = 1$.

In accordance with the formula (2), in case with no pipes ($K_{PIP} = 1$), we obtain:

$$I_{CL.CAP} = K_{SCR} \cdot K_{CIR} \cdot K_{DEP} \cdot K_{TER} \cdot K_{PIP} \cdot I_{CL.CAP.ID}$$

$$I_{CL.CAP} = 1 \cdot 1 \cdot 0.95 \cdot 0.74 \cdot 1 \cdot I_{CL.CAP.ID} \approx 0.7 \cdot I_{CL.CAP.ID}$$

Table 1 shows that the CL core cross-section $F_C = 630$ mm^2 will be sufficient, since it will provide $I_{CL.CAP.ID} = 865$ A:

$$I_{CL.CAP} = 0.7 \cdot I_{CL.CAP.ID} = 605 \text{ A}$$

i.e., the condition is met:

$$I_{CL.CAP} = 605 > 588 = I_{CL}$$

Let's assume that the calculation of the network operation mode and the selection of CL cables were not coordinated, and the designer considered that the current $I_{CL} = 588$ A passes not in one, but simultaneously in two CL circuits. If the distance between the circuits is 0.4 m according to [1], $K_{CIR} = 0.85$ will be. Then, in accordance with formula (1), we get

$$I_{CL.CAP} = 0.6 \cdot I_{CL.CAP.ID}$$

and Table 1 shows that the core cross-section $F_C = 1000$ mm^2 will be sufficient, since it will provide $I_{CL.CAP.ID} = 1050$ A:

$$I_{CL.CAP} = 0.6 \cdot I_{CL.CAP.ID} = 630 \text{ A}$$

which is greater than the current $I_{CL} = 588$ A, i.e., the condition is met:

$$I_{CL.CAP} = 630 > 588 = I_{CL}$$

So, the inconsistency of the network operation mode and the CL thermal calculation would lead to the fact that instead of a cable with a core 630 mm^2, a cable with a 1000 mm^2 would be used, which costs significantly more.

6. CONCLUSIONS

The above reasoning shows that unloaded CL appear due to excessive reserves, which are laid at two stages of CL design.

1. When choosing the CL load current I_{CL}, uses such network operation modes, which, although possible, but with minimal probability. For example, is it really possible for the aged overhead line to carry the load current that corresponds to its original current-carrying capacity? It's impossible and it means that I_{CL} shouldn't be equal to overhead line current-carrying capacity and could be less. Or, for example, how realistic is it that when one of the circuits of a double-circuit CL is put into repair, it turns out that it was at this time that the electrical load of the powered substation reached a certain maximum predicted for the future (for instance, for the 2030 year, while today we have only 2000)?

2. The conditions for obtaining CL load currents I_{CL}, which the projected CL must withstand, are often overlooked by those specialists who are engaged in thermal calculation, selection of the CL core cross-section and other cable parameters. First of all, we are talking about inconsistencies in the ambient temperature and the number of CL circuits in operation. As a result, obviously impossible and extremely unfavorable CL cable cooling conditions fall into the calculations – positive air temperature at the time of the winter load maximum, etc., which leads to an underestimation of the CL core current-carrying capacity and an overestimation of the CL core cross-section for this reason.

According to the results of the "reserves", which are laid down in paragraphs 1 and 2, it turns out that in normal operation mode the CL is operated with a core load current several times less than its current-carrying capacity. Such a big difference between CL load and CL current-carrying capacity means that even if we assume that there will be a repair or post-accident operation mode and the CL load current will increase significantly, anyway XLPE insulation temperature of the CL will still be less than 90°C.

Underutilization of insulation capabilities is wasteful, because the cost of CL is up to 1 million euro per each kilometer of the route. Therefore, as soon as possible, it is necessary to restore order in the selection of CL cables, and at all stages – from the calculation of operation modes and development of requirements for load currents (search for current I_{CL}) to the selection of cable with enough current-carrying capacity (that provides $I_{CL.CAP} > I_{CL}$).

As part of the correction of the current situation, close attention should be paid to the system of correction coefficients used when selecting cables from catalogs, the values of these coefficients and the conditions of their application.

In particular, it is believed that CLs laid in polymer pipes have a reduced current-carrying capacity compared to laying directly in the ground due to the presence of an air gap in the pipe between the cable and the pipe. In practice, many pipes with cables are filled with groundwater, and there is no air in them. Therefore, with a high groundwater level in formula (1), it makes sense to replace the well-known correction factor $K_{PIP} \approx 0.9$ with a new value of $K_{PIP} \approx 1$, thereby winning about 10% of the CL current-carrying capacity. It is also advisable to consider the issue of forced filling of polymer pipes with clean water, which will not only improve the cable cooling conditions and increase the current capacity, but also simplify its removal cable from the pipe if necessary.

Another point that it is desirable to take into account in formula (1) and the like is the ability of CL to overload. So, according to the standard SRT 56947007-29.060.20.072-2011 "Power cable lines of 110-500 kV. Organization of operation and maintenance. Norms and requirements", posted on the website of JSC "FSK EES", overheating of XLPE insulation up to 105°C is allowed.

Of course, cable factories are comfortable with the state of affairs that exists in the networks – when expensive lines are almost not loaded. It is because the profit of the plants is great, and the risks of incurring warranty obligations are minimal. Therefore, you should not expect that tables with correction coefficients for overload will appear in cable catalogs, but such coefficients can be added into standard of the grid companies because companies are interested in maximizing the use of their funds invested in construction, which will put cable factories in front of the fact – either agree or leave the market.

According to the author's estimates, the admissibility of the CL short-term overload and an increase in the XLPE insulation temperature from 90°C to 105°C will increase CL current-carrying capacity by 10-15%, i.e., the new increasing correction factor should be put into the formula (1) and will be equal to 1.1-1.15 p.u., which is quite noticeable.

I would like to draw attention to another feature of CL: from Table 1 it can be seen that a decrease in the requirements for the cable current-carrying capacity is accompanied by a noticeable decrease in the core cross-section. For example, if the current of 1215 A is acceptable for a cable with a core of 1200 mm^2, then when the current is reduced by 1.25 times to 960 A, the sufficient cross-section of the core is reduced to 800 mm^2 – by 1.5 times! Therefore, at the same load currents I_{CL}, entering into formula (1) the correct correction coefficients for laying in pipes and for overload will allow, without violating the conditions $I_{CL.CAP} > I_{CL}$, to use cables with a reduced core cross-section, and not only by 1 step on the scale of typical core cross-sections, but sometimes by 2-3 steps.

Reducing the cross-section of the core allows you to save on copper for the cable, on expensive XLPE insulation, the volume of which, with a known thickness of the insulation layer, depends on the cross-section of the core. There is also a decrease in the weight and diameter of the cable, the outer diameter of polymer pipes for HDD decreases, the maximum construction length increases, the number of cables joints along the route decreases.

So, the correction of the coefficients' system and the search for reasonable algorithms for designing CL will make it possible to more effectively use the remarkable properties of XLPE insulation designed for long-term operation at a temperature of 90°C and overloads up to 105°C. Nationwide, this will have a huge effect, achieved by saving on the cable core cross-section and the volume of its XLPE insulation.

REFERENCES

1. ABB user Manual "Cable systems with cross-linked polyethylene insulation", 2010.
2. Titkov V.V., Kosorukov A.V. "Thermal calculation of cable lines" // "The Electrical Engineering News" magazine, No.3(87), 2014.
3. Dmitriev M.V. "Screen grounding for 6-500 kV single-core cables" // St. Petersburg: Publishing House of Polytechnic University, 2010, 152 p.
4. Dmitriev M.V. Metallic screen selection for 6-500 kV cables taking into account the aperiodic current // "The Electrical Engineering News" magazine, No.4(88), 2014.