APPLICATION FEATURES OF CABLES WITH CROSS-LINKED POLYETHYLENE INSULATION

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Currently, has accumulated considerable experience in the operation of cable lines with cross-linked polyethylene insulation, and now there is an opportunity to discuss their advantages and disadvantages, as well as to make a comparison with paper-oil insulation cables. There are many high-level specialists, and each of them has their own opinion about polyethylene insulation. I hope that the considerations outlined here will become a reason to start an open discussion on the pages of the magazine "ELECTRICITY. Transmission and Distribution" about whether we are doing everything right in our cable networks.

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Introduction

Comparing cables with cross-linked polyethylene (XLPE) insulation with cables where paper-oil insulation (POI) is used, as a rule, several of the following advantages of XLPE are mentioned:

– higher permissible temperature in normal operation and in case of short circuits (higher cable current capacity and short circuit thermal stability);
– no restriction on the height difference along the cable line (CL) route;
– easy installation (especially single-core cables) and operation;
– less dielectric permittivity of insulation (lower "no-load" current);
– less tangent of the dielectric loss angle (lower insulation power losses);
– environmental safety due to the lack of oil.

Of course, XLPE has disadvantages, but they have always been talked about less willingly and certainly not as loudly as about the advantages. It is quite possible that Russia was perceived as a very attractive market for manufacturers and suppliers of such cables, and therefore interested parties maintained a positive image of cables with XLPE insulation. Probably, it was in the hands of some power grid stuff who reported on the successful implementation of "innovations".

It is advisable to deal with XLPE and, if necessary, adjust the technical policy right now, since grid companies are closely engaged in optimizing their costs for the construction and operation of cable networks.

If earlier it was necessary to take on faith catalogues and presentations of factories that testified exclusively to the remarkable properties of power cables with XLPE insulation, now is the time to think about whether these cables are so good and what is the scope of their rational application?

Quite often, in justification of the remarkable properties of XLPE, they referred to positive world experience (forgetting to say that a number of countries have been and remain staunch supporters of POI). However, now it is possible to judge about the XLPE insulation on the basis of domestic experience in the production, design, installation and operation of such cables, which showed:

- there is no production of XLPE in Russia, and therefore 100% of the raw materials for cables and couplings (joints, terminations) are imported from abroad;
- in Russia, more than a dozen factories, having purchased imported technological lines, can produce "XLPE cables" 6-35 kV, only a few can produce "XLPE cables" 110 kV and above, but the production of "XLPE couplings" is clearly lagging behind, and until recently couplings of classes 110 kV and above in country were not released at all;
- cables with XLPE insulation turned out to be not cheap at all, and their cost in some cases is one and a half to two times higher than cables with POI;
- the damage rate of 6-500 kV cables with XLPE insulation, contrary to all expectations, was not lower, and sometimes even higher than that of cables with POI.

An unfavorable circumstance accompanying the use of XLPE insulated cables in Russia was also the fact that for many years the regulatory documentation clearly lagged behind intensive construction, and many CL were created "blindly". Of course, in such conditions it was not possible to do without costly mistakes, because the cost of a CL reaches up to 1 million-euro for each kilometer. For example, there are cases of damage to the line immediately for a significant length of the route for the following reasons:

- incorrect selection of core and/or screen cross-section;
- incorrect choice of the grounding/bonding scheme of the screens in terms of accounting for induced currents and power losses caused by them;
- erroneous tests of XLPE insulation with increased DC voltage according to the norms valid for old cables with POI.

Another important point that finally began to be discussed was the method of neutral grounding in medium voltage networks of 6-35 kV. It turned out that cables with XLPE insulation (especially single-core construction) are not quite suitable for domestic 6-35 kV networks operating with insulated (compensated) neutral. The positive foreign experience on cables with XLPE insulation, which has always been set as an example to domestic power engineers, actually refers to networks in which the fault to ground is quickly and selectively switched off by relay protections, i.e. refers to networks:

- high and ultra-high voltage with a deadly grounded neutral;
- medium voltage with resistively grounded neutral.

Let's consider the listed issues in more detail.

Cable design

Unfortunately, the mass use of cables with XLPE insulation in our country occurred for years, when, firstly, the qualification of design centers fell, and secondly, there was not enough regulatory documentation and standards.

The weakening of the design school in the 90s and the lack of norms where it would be clearly written how to deal with polyethylene, expectedly led to a number of unsuccessful projects, which, of course, made us doubt the advantages of cables with XLPE insulation. But here we have to learn to divide the problems into those related to the cables themselves and those caused by project errors.

Talking now about the advantages and disadvantages of cable XLPE insulation in comparison with POI, of course, we must understand that many of those mistakes are now hardly possible. Therefore, in terms of design, perhaps, at present, cables with XLPE and POI are on an equal position.

This does not mean that all the necessary documents have been developed and the designers no longer have problems.

Cable production

There is not a single manufacturer of high-quality polyethylene in Russia to the extent that it is needed in the manufacture of power cables. Therefore, without exception, all cable plants import raw materials, buying it from only two companies – Borealis (Europe) and DOW (America). Moreover, the first accounts for 75% of deliveries. Thus, if we completely abandon cable paper isolation, then Russia will become colossally dependent on Western manufacturers, sanctions, and supply conditions.

Even a few years ago, when exchange rates facilitated painless purchases of raw materials abroad, a 10 kV cable with XLPE insulation, for example, cost one and a half times more expensive than a cable with POI. Now, in 2015, taking into account the rise in the cost of foreign-made raw materials, the difference in cost has increased.

Another important point that affects the cost of the cable is the price of copper. It turned out that, although Russia has its own copper production, cable factories are forced to buy copper for cores and screens on the London stock exchange, which automatically links the cost of copper to the exchange rates of world currencies. This specificity leads to the fact that even the cost of a conventional cable with POI and a copper core, all components for which are domestic, is determined by the dollar and euro exchange rates.

The origin of XLPE and the high price of a cable with such insulation should make us think about whether our country needs the mass use of polyethylene. It seems rational to determine the range of tasks for which polyethylene really has no equal, and in other cases, let inexpensive cables with POI be used.

The high price of cables with XLPE insulation automatically regulates the scope of application of XLPE in the domestic electric power industry, but it would be great if our networks were built not by economists, but by technical specialists. Therefore, in any case, it will be useful to finally formulate the technical policy of large electric grid companies in terms of cables, which would clearly state when and why it is necessary to use XLPE, and when and why – POI.

Most likely, during the construction of 110-500 kV CL, the share of XLPE insulation in the foreseeable future will be very high, but in 6-35 kV networks, especially if there is an isolated (compensated) neutral, cables with POI may well occupy a significant niche.

Cable joints and terminations

The competition in the market of power cables with XLPE insulation in Russia is very tough. Many domestic and foreign factories are ready to supply power cables with XLPE insulation for different voltage classes, in single-core and three-core versions. If we talk about competition in the cable coupling market, there are noticeably fewer manufacturers here, especially domestic ones, and this is not accidental. The fact is that the coupling is a responsible element of the CL, and it is more difficult to make it than a cable.

If we compare the installation of a coupling for a cable with POI and a coupling for a cable with XLPE insulation, then the installation of the latter is easier. It is not entirely clear how then to explain the large number of coupling damages on lines with XLPE insulation. Installation organizations blame for everything the coupling manufacturers, and, on the contrary, manufacturers see only poor-quality installation.

It is necessary to understand this issue, since damage to the coupling (see Fig.) means a short circuit on the line, and every time the cable experiences both thermal and dynamic effects of short-circuit currents over a large length of its route, which does not benefit it.

Without understanding the reasons for the high emergency statistics on couplings, it is impossible to be completely objective in assessing the advantages and disadvantages of cables with XLPE insulation, as well as their comparison with POI cables.

Figure. Single-core 10 kV cable after removing parts of the damaged coupling from it.

Cable testing and fault locating

The appearance of XLPE insulation in networks required a revision of approaches to testing and searching for cable damage. The fleet of devices and instruments that were used to service cables with POI turned out to be unsuitable for XLPE insulation, which does not tolerate tests with high level DC voltage, does not tolerate the search for insulation damage by the traditional method of burning. Also, certain features in the maintenance of cables with XLPE were introduced by the presence of copper screens, which was not the case with POI cables.

After incorrect tests and the search for damage led to the loss of several CLs, it was possible to restore order in this matter, and now the corresponding special equipment of domestic or foreign production are used to service CL with XLPE insulation.

So, throughout the country, tests of XLPE insulation are now carried out with an ultra-low frequency voltage of 0.1 Hz. In addition, methods of damage detection that are not dangerous for XLPE have been significantly developed.

Having dealt with the test methods, the experts wondered if it was necessary to test cables with XLPE insulation as often as it was done for POI? The fact is that any high-voltage test leaves defects in the insulation, and if the insulation is solid (XLPE), then such defects are not capable of self-healing and will only progress over the years. Therefore, a promising direction of gentle diagnostics of CL by the method of partial discharges began to develop in Russia. Thus, in relation to the XLPE, there has been a tendency to replace tests with increased voltage to diagnose the cables under continuous operating voltage without disconnecting it from the network. But even such a cable-safe procedure still makes sense only in the first years after the start of work.

So, if we compare cables with XLPE insulation and POI, then their operation should be built differently. It is impossible to replace the POI cable with a modern cable with XLPE insulation, but at the same time maintain network maintenance methods involving multiple insulation checks, because an important advantage of XLPE is precisely that it does not need to be approached.

The ideology of the use of XLPE should be as follows: the cable with XLPE insulation does not require maintenance. The exception is the first 2-3 years of its operation, when it makes sense to diagnose the main insulation by partial discharges, as well as testing the outer sheath for integrity with DC voltage of 10 kV.

Such a policy in relation to XLPE is really justified, and this is confirmed by foreign network companies. It is the large savings on operating costs that gives reason to spend money on the purchase of cables with XLPE insulation, although they are more expensive than cables with POI.

And how is it in Russia? Not only do we buy and lay an expensive cable with XLPE insulation, but we also begin to organize its operation, providing ourselves and contracting firms with work for many years to come:

– the insulation and the cable sheath are regularly tested, for which the line is taken out of operation, the circuit is being prepared, the bonding of the screens is being dismantled;
– cable couplings are hung with expensive sensors for monitoring partial discharges;
– the CL itself is equipped with a continuous temperature control system (the price of such an installation is huge, it is a percentage of the cost of the cable, and the effectiveness is questionable, since most of the CL in our country are loaded no more than just 0.3-0.5 of their nominal current capacity).

I think that cables with XLPE insulation will become really attractive only when their use is associated with the desire to simplify and reduce the cost of operation, and not with the desire to make money on it.

Neutral grounding and cable insulation

Cables with XLPE insulation are designed primarily for use in power networks with grounded neutral (deadly, effective, resistive). In networks with isolated (compensated) neutral, their use causes difficulties.

Firstly, the isolation of any equipment of such a network should be calculated for long-term exposure not to phase voltage, but linear. For cables with XLPE insulation, given the high cost of polyethylene, such a rise in price is noticeable.

Secondly, the insulation must be resistant to arc overvoltages (due to unstable burning grounding arc at the point of damage) and switching overvoltages (due to the need to find a place of network insulation damage by alternately disconnecting feeders). At the same time, XLPE insulation, which, unlike paper-oil, is not capable of self-healing, has insufficiently confident positions here, and any defects in XLPE insulation will progress when exposed to overvoltage and sooner or later may damage the insulation.

The transition in the medium voltage network from an isolated (compensated) neutral to a resistively grounded one would allow selectively disconnecting faults to ground, which would minimize the duration of the impact on the cable insulation of network line voltage and overvoltages, would allow to have less expensive and more reliable, durable cables.

Neutral grounding and single-core cables

Cables with XLPE insulation are available in both three-core and single-core versions, but in the latter – much more often. So, 100% of cables for 110-500 kV networks are made single-core, and in 6-35 kV networks the share of single-core can reach 50%. Single-core cables are simpler and more reliable than three-phase ones, but they have one feature – copper well-conducting screens in which currents of 50 Hz are induced and losses of active power caused by currents occur. The currents and losses would be minimal only if the cables had a small screen cross-section. However, unfortunately, cables with a large screen cross-section are widely used in networks, which is caused by the need to ensure the thermal stability of screens to short-circuit currents.

In 110-500 kV cable networks with a grounded neutral (there are no 750 kV cables in Russia), the screen cross-section is selected according to the stability to the current of a single-phase short circuit, taking into account the time of its disconnection. As a result, the screen cross-section sometimes reaches 240-300 mm^2, and there are problems with currents and losses in screens in normal operation, where, on the contrary, a small screen cross-section of up to 35-50 mm^2 would be good.

In 6-35 kV networks with isolated (compensated) neutral, single-phase fault to ground currents are small and amount to units or tens of Amperes. So, it would seem that in such networks it is enough to use single-core cables with small cross-sections of screens and, as a result, not have problems with currents and losses in the screens in normal operation. Unfortunately, it doesn't work out.

If a single-phase insulation damage occurs, due to small fault to ground currents it is difficult to detect it. The long-term existence of a short circuit leads to the fact that under the influence of the line voltage of the network, as well as arc and switching overvoltages somewhere else in the network, a second fault to ground occurs in the intact phase, and then the network receives a double short circuit. It is for double short-circuit currents that one has to choose the cross-section of the screens of single-core cables with XLPE insulation, and these currents reach 0.87 of the three-phase short-circuit current. Screens are obtained with a large cross-section, and cables are more expensive. In addition, a large cross-section of the screen with its two-ends grounding leads to the appearance of induced 50 Hz currents in the screens and the parasitic losses of active power caused by them in the screens, the annual cost of which reaches 10 000 euro from each kilometer of the line.

So, in 110-500 kV networks, the cross section of the screens of single-core cables is selected for a single-phase short-circuit current, and in a 6-35 kV network with an isolated neutral – for a double short-circuit current (almost a three-phase current). In both cases, the screen cross-section is increased, and, consequently, such cables have problems with currents and power losses in the screens in the normal operation of the network. To combat losses, it is necessary to introduce measures such as one-end screens grounding or screens cross-bonding, which require careful selection and careful operation. In other words, first you need to overpay for the cable by buying it with a large screen cross-section, and then you still have problems with losses, which, again, you need to spend money to combat.

In 110-500 kV networks, the costs of implementing and maintaining measures to combat currents in screens are negligible compared to the cost of a CL, but in 6-35 kV networks, especially given the huge number of such cables, mass implementation of measures to combat currents in screens would be undesirable (although individual cases are already known, and their economic expediency has been proven).

If the 6-35 kV networks had not an isolated (compensated) neutral, but resistively grounded (as in those countries from where XLPE came to us), then the screen cross-section could be selected for single-phase fault currents of no more than 500-1000 A, and not at all for double short-circuit currents approaching the value to the current of a three-phase short circuit in tens of kA. This would allow the use of single-core cables with a small screen cross-section, and in normal network operation it does not cause problems with losses in the screens and does not require the introduction of inconvenient measures to combat them, i.e. cable screens can simply be grounded at the both ends without fear of consequences.

Unfortunately, a massive transition in domestic networks of medium voltage 6-35 kV to resistive neutral grounding is not yet expected, which means that in such networks it is necessary to use not single-core cables, but three-core ones. These can be cables with XLPE insulation or POI – any, but only three-core, not single-core.

In favor of three-phase cables, there is another problem that urban cable networks operating with an isolated neutral are now facing. If a fault to ground occurs in a three-phase cable, due to the compactness of the design, the insulation damage quickly passes to the second and third phases (in the same place of the cable), and the cable is promptly disconnected by current relay protections. In other words, in the case of three-phase cables, the problems of finding a fault to ground in the network are minimized for the operating organization, because it is enough to wait a little and the emergency cable will manifest itself. If you use single-core cables, especially laying them at a distance from each other (and not in a closed triangle), then the fault to ground of one of the phases is unlikely to spread to other two phases of the same cable, and then the emergency cable will no longer manifest itself, and you need to search for it. In the process of such a search, it will be necessary to turn off all the network cables one by one, reducing the reliability of operation, generating the risk of another fault to ground somewhere else in the network on the initially intact phase.

The above considerations complement the arguments against single-core cables in networks with isolated (compensated) neutral, and incline to the use of three-phase cables in such networks or to change the neutral mode.

Conclusions

If the mass introduction of XLPE insulation in our country followed not before, but after clarifying the features of this type of insulation, then cables with XLPE and POI would have clearly formulated areas of rational use and used for their intended purpose.

Cables with XLPE insulation do have a number of advantages, such as the ability to work at elevated temperatures or the absence of restrictions on the height difference along the CL route, but there are also a number of very unpleasant circumstances that should not be ignored, but should be discussed and, if necessary, make appropriate adjustments to the normative documentation and standards.

Comparing XLPE insulation with POI is not the easiest question. However, some conclusions can be drawn already now.

1. We should try to objectively understand the causes of large damage statistics on CL with XLPE insulation and understand what is the matter.
2. The cable with XLPE insulation should be perceived as maintenance-free in operation. In particular, with the exception of the first years of operation, it is necessary to minimize the testing of such cables. Also, the equipping of such CL with continuous monitoring systems should not be encouraged, since they contradict the very ideology of the use of XLPE insulation.
3. In medium-voltage networks of 6-35 kV, the use of single-core cables with XLPE insulation is rational only in the case of resistive grounding of the neutral, configured to quickly disconnect the fault to ground.
4. In medium-voltage networks of 6-35 kV with insulated (compensated) neutral, three-phase cables (with XLPE insulation or POI) should be used more widely, moving away from single-core ones.
5. In medium-voltage networks of 6-35 kV, in some cases, cables with POI could compete with XLPE, at least because of the low cost, resistance to overvoltage. It is recommended that grid companies decide where it is better to lay POI cables and indicate this in the technical policy, including taking into account the importance of reducing the import of raw materials.
6. In 110-500 kV networks, there is no alternative to single-core cables with XLPE insulation in the foreseeable future.