TYPICAL MISTAKES WHEN PERFORMING GROUNDING OF SINGLE-CORE 6-500 kV CABLES. PART 1

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The number of 6-500 kV lines with single-core cables with cross-linked polyethylene (XLPE) insulation is increasing, respectively, the experience of operation is accumulating. After analyzing the available information, let's talk about typical mistakes when choosing and implementing screens bonding/grounding schemes.

Keywords: cable line, single-core cable, cross-linked polyethylene (XLPE), cable screen, screen grounding, screens cross-bonding, link box.

1. INTRODUCTION

With the increasing use of single-core cables with cross-linked polyethylene (XLPE) insulation in the construction of medium and high voltage lines, problems associated with mistakes of design organizations, poor-quality equipment, careless installation, etc. are increasingly becoming apparent. If we exclude the repetition of at least the most common mistakes, then this will significantly increase the efficiency and reliability of cable lines.

The design of a single-core cable is simplified in Fig.1, and Fig.2 shows the basic schemes of screens bonding/grounding [1, 2]. As an example, Fig.2 shows a line having three cable construction lengths. They are connected to each other depending on the adopted scheme of screens bonding/grounding: either with the help of simple cable joints (CJ), or with the help of special cross-bonding cable joints (CBJ) having a rupture of the screen and the output of its ends to outside. There are also cable terminations (CT) shown on Fig.2.

In places where cable line screens are ungrounded (Fig.2b) or cross-bonded (Fig.2c), to protect the cable outer sheath from impulse overvoltages, metal-oxide surge arresters (MOA) are installed, which are placed inside special boxes – end link-boxes (ELB-MOA) or cross-bonding link-boxes (CBLB-MOA). Connection of each screen with its protective MOA is performed by a special connecting wire (CW) with polyethylene insulation.

Let's consider typical mistakes when creating screens bonding/grounding schemes.

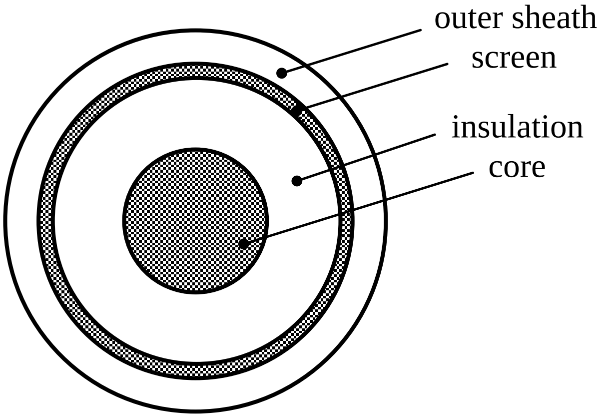

Fig.1. Design of a single-core 6-500 kV cable.

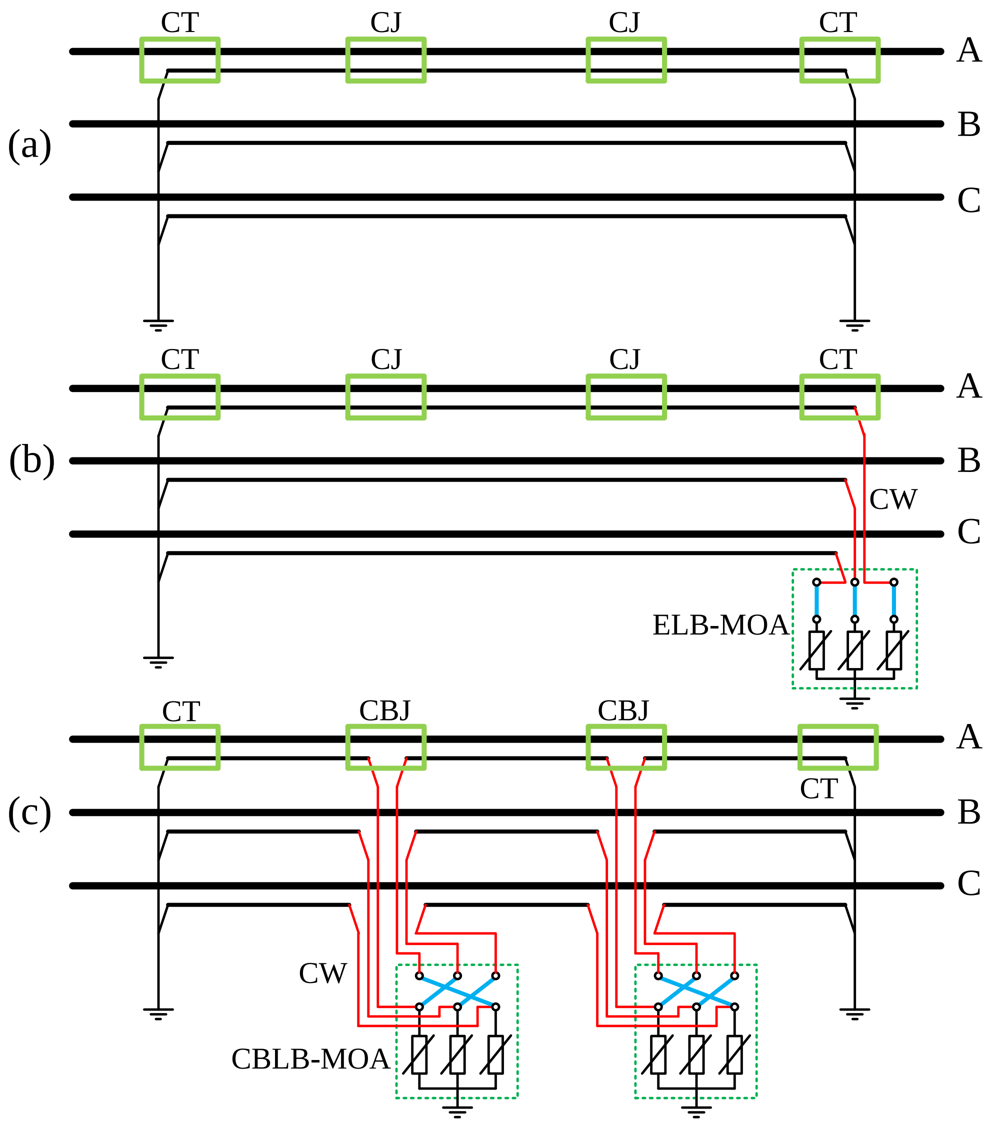

Fig.2. Typical screens bonding/grounding schemes for 6-500 kV cable lines with single-core cables:
(a) – two-side grounding;
(b) – one-side grounding;
(c) – screens cross-bonding.

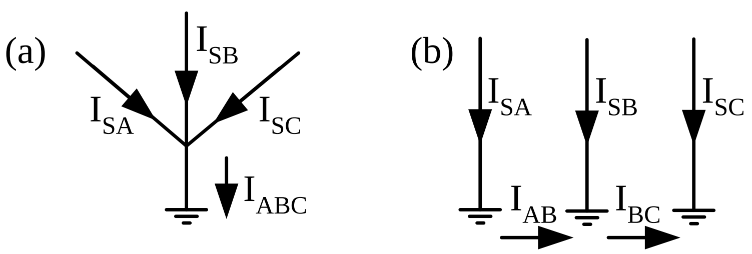

Fig.3. Possible options for connecting screens to the grounding device:
(a) – connecting screens to the ground using one common conductor;
(b) – connecting each screen to the ground separately from two others.

2. SELECTION OF SCREENS BONDING/GROUNDING SCHEME

Two-side screens grounding (Fig.2,a)

Two-side screens grounding scheme (Fig.2a) is the simplest, but it has a significant drawback: industrial frequency (50 Hz) currents are induced in screens, creating additional active power losses and causing:

– limitation of the cable current capacity according to the insulation heating condition;
– the need to pay for these losses.

Thus, the use of screens two-side grounding is an erroneous technical solution.

In addition, even if the scheme of Fig.2a is applied reasonably, it often has an ill-conceived design of the grounding nodes. For example, if there is no current I_{ABC} in the grounding circuit in the normal steady-state operation mode (Fig.3a), then in the diagram of Fig.3b, equalizing currents I_{AB} and I_{BC} will already pass through elements of the grounding circuit, which will heat its steel elements above the temperature of the copper cable screen.

As an example, Photo 1 shows a 10 kV double-circuit line laid from two 110/10 kV transformers to two 10 kV busbars sections (in each phase of the line, there are three single-core cables at once to provide the necessary current capacity). Screens of line phases are grounded to various sections of the metal supporting frame, which caused them to overheat.

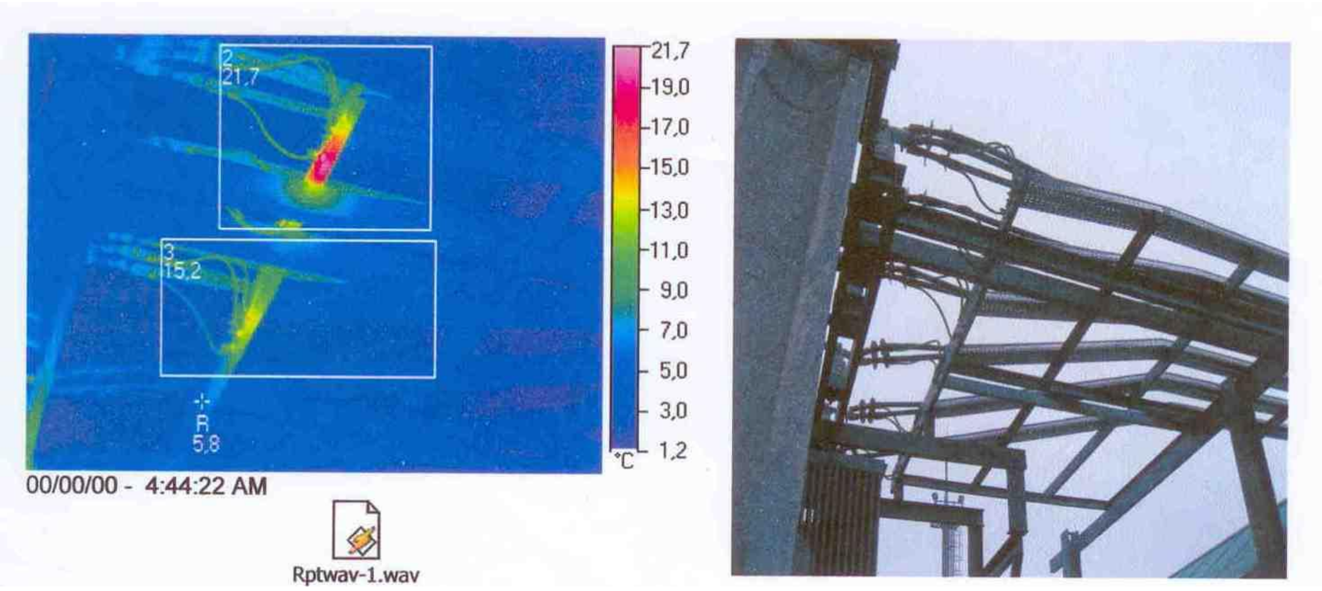

Photo 1. The results of thermal inspection of the grounding node of a 10 kV cable line.

One-side screens grounding (Fig.2,b)

The scheme in question (Fig.2b) lacks the disadvantages of the previous one, however, it is applicable only for cable lines of small length due to the need to limit the power frequency (50 Hz) induced voltage at the end of the screen relative to the ground, which is proportional to the length of the cable and the magnitude of the short-circuit current.

To increase the length of cable lines at which this one-side screens grounding can still be used, two methods are proposed in [1, 2] to reduce the induced voltage of the industrial frequency (50 Hz) on the screen relative to the ground:

– cable separation into K>1 series-connected sections, each of which has one-side screens grounding [1, 2];
– laying of a metal grounded bus [3] parallel to the cable line.

When dividing screens to K sections, the voltage on the screen relative to the ground decreases in direct proportion to the increase in the number of sections K. However, at the same time, due to screen sectionalization, cable outer sheath electric tests and the search for its damage become noticeably more complicated, since access to sectionalization points for the purpose of connecting equipment is required for the timespan of their implementation. All this, from the point of view of construction and operation costs, brings the K>1 solution closer to screens cross-bonding. Since screens cross-bonding effectively reduces the induced voltage on the screen relative to the ground, the solution K>1, as a rule, is not profitable, partly even erroneous.

As for the metal bus, some foreign manufacturers insist on its use together with their cables. It is shown in [3] that the bus allows reducing the voltage of the industrial frequency induced on the screen only in one case – with a single-phase short-circuit in a 110-500 kV network with a grounded neutral, and the decreasing of the induced voltage is not more than 1.5-2.0 times compared with the case of absence of the metal bus.

Not fully understanding the purpose of such a bus, a number of design organizations are led by foreign cable manufacturers and mistakenly provide it even for those 110-500 kV cable lines that have a single-phase short-circuit induced voltage on the screen relative to the ground with a margin less than permissible.

Screens cross-bonding (Fig.2,c)

The circuit (Fig.2c) also has no induced currents and active power losses in screens, but is used in cases where the inexpensive circuit Fig.2b (and its variations) has dangerous voltage on the screen relative to the ground. Fig.2c shows one complete cross-bonding cycle N=1, when (3N–1) nodes with link-boxes divide the line route into 3N sections. To limit the voltage on the screen relative to the ground in the node of cross-bonding (it's proportional to the length of the cable section between the cross-bonding nodes and the value of the short-circuit current of the network), sometimes several complete cycles N>1 are required.

The efficiency of screens cross-bonding decreases in the following cases:
– lengths of the sections between cross-bonding nodes differ;
– distances between phases (the method of laying) differ from one line section to another (for example, due to the presence of trenches and horizontal-directional drillings HDD).

In these cases, there are currents appear in screens and power losses caused by them.

In [4] it was shown that the difference in lengths of sections between cross-bonding nodes, which occurs in practice, or the difference in methods of laying, is not catastrophic and cannot be considered as a reason for refusing the cross-bonding. Therefore, the attempt of some specialists to rigidly demand the fulfillment of the criteria of an ideal cross-bonding (equal lengths of all sections, the same method of cable laying) should be recognized as erroneous – an irregular cross-bonding is quite workable.

This is important to understand, because in conditions of dense urban development, there are large number of obstacles (roads, rivers, etc.) which need to be crossed by HDD – thus, only an irregular screens cross-bonding can be implemented in practice.

There are also cases when it is not possible to find a place to implement a complete screens cross-bonding and the number of sections turns out to be not a multiple of three.

For example, such an irregular cross-bonding may have one node that divides the cable line route into two sections of approximately equal length. This solution can be used for cable lines where screens one-side grounding no longer "acceptable" due to the increased induced voltage on the screen relative to the ground, and the full screens cross-bonding cycle is not yet possible due to the small length of the cable line and the lack of a sufficient number of cable joints.

As it was proved in [1], if the cable line has only one cross-bonding node dividing the line to two sections of equal length, then induced currents in screens are reduced by 2 times, and the power losses in screens are reduced by 4 times compared to the original case of two-side grounding of screens – this is a pretty good result, and it can be shown that such a cross-bonding is advantageous and expedient compared to the scheme of Fig.2a.

Another example of an irregular screens cross-bonding can be the diagram of Fig.4, which had to be recommended for one of 110 kV cable lines with a length of 3 km.

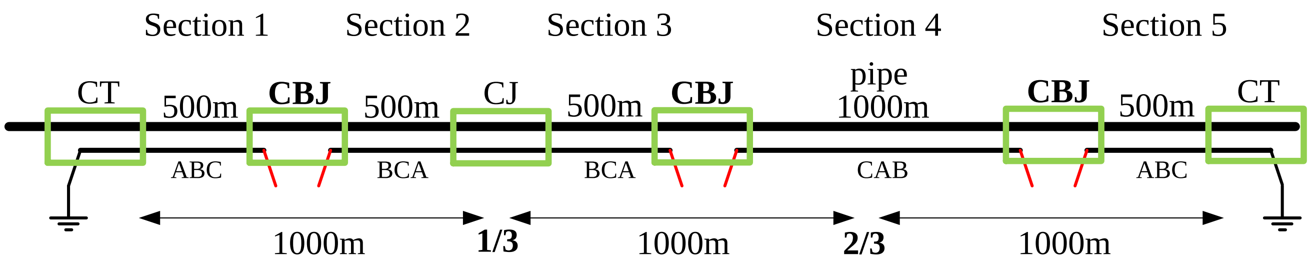

Fig.4. Example of irregular screens cross-bonding cycle.

It was not possible to perform the "usual" screens cross-bonding with the division of the cable route into three sections of approximately equal length, since it was not possible to install cable joints at the mark of 2/3 cable route due to a puncture under the river. Despite this, it was possible to achieve zero induced currents and zero losses in screens for the entire line, that is, exactly the same indicators that a line with an ideal screens cross-bonding has.

In the diagram of Fig.4, as well as for the ideal screens cross-bonding, for each of the three possible sequences of phase alternation (ABC, BCA, CAB), total lengths of cable sections are the same and equal to 1000 m:

- ABC is available on the first (500 m) and fifth (500 m) sections;
- BCA is available on the second (500 m) and third (500 m) sections;
- CAB is available on the fourth (1000 m) section.

So, when designing 6-500 kV cable lines, you can use any variants of screens cross-bonding schemes (ideal or irregular, complete or incomplete), but only if there are justifying calculations. In general, the requirement to have an exceptionally perfect complete screens cross-bonding is erroneous.

3. CHOOSING THE NUMBER OF SCREENS CROSS-BONDING CYCLES

Of particular note are technical solutions where cable line screens cross-bonding with an overestimated number of N cycles is used. For example, a cable line with cables of foreign production is known in the country, which has full 5 cycles of screens cross-bonding – it means that14 transposition nodes divide the cable route into 15 sections. Calculations of the voltage induced on screens of this line showed the sufficiency of only 1-2 cycles, but the cable manufacturer, taking advantage of its leading position in the market, insisted on using 5 cycles at once (respectively increasing the number of cross-bonding joints and link-boxes supplied of its production), without presenting any technical arguments in favor of such a solution.

A similar example are technical seminars on cable lines conducted by a very well-known European company, where designers are convinced that screens cross-bonding nodes should be equipped every 500 m of the length of the cable line. Such statements bring to absurdity the excellent idea of screens cross-bonding, because the maintenance of a cable line with such a number of cross-bonding nodes is extremely difficult, because any cable tests require pumping water from link-box wells, opening link-boxes (the need to unscrew from 15 to 30 bolts) and disconnecting MOAs installed in the box. Because of this, only the preparation of the cable line for testing can take several days, during which the line will be disconnected from the network, the staff will be busy with hard work, and the consumer will be powered according to a temporary grid scheme with reduced reliability.

If we talk about the origin of the specific number "500 m", then, apparently, it is the following. In the most unfavorable case, when the single-core cables are laid in a row at a great distance from each other, and the short-circuit current of the network is too much high up to 80-100 kA, the voltage induced on the screen relative to the ground at the node of the cross-bonding of the cable line with a length of 1500 meters will reach 5-7 kV (according to [1, 2]), which is considered the maximum permissible for the cable outer sheath. So we divide 1500 m to three sections and we have a rule "link-box for each 500 m of cable route".

Thus, reasons why a number of foreign manufacturers "push" us to an overestimated number of cross-bonding cycles are clear:

– it is not necessary to carry out any justifying calculations on the choice of the number of cross-bonding cycles, because the proposed "500 m" rule guarantees "success" (induced voltage on screens relative to the ground will be lower than permissible value);
– the induced voltage on screens relative to the ground and the probability of cable outer sheath breakdown are reduced, i.e., risks for cable producing companies of a situation when it is necessary to fulfill warranty obligations are reduced;
– the volume of supplies of expensive equipment (cable joints, link-boxes) is increasing.

Since often the supplier of the cable to the facility is known even before the bidding, this is what allows him to dictate with impunity and categorically to middle-level technical specialists (designers) profitable solutions for himself, ignoring the requirements to submit justifying calculations.

4. SELECTION OF METAL-OXIDE SURGE ARRESTERS

Any non-linear metal-oxide surge arrester (MOA) is designed to protect the insulation of equipment only from impulse overvoltages and is not intended to limit voltage increases of industrial frequency (50 Hz).

These are functions performed by MOA installed between screens and the ground in cable end link-boxes (ELB-MOA) and cross-bonding link-boxes (CBLB-MOA). Its purpose is to protect the cable outer sheath from impulse (lightning and switching) overvoltages that are transmitted there from the cable core and cable main XLPE insulation.

The thickness of the outer sheath of a single-core 6-500 kV cable practically does not depend on the class of its rated voltage and is about 5-6 mm, which from the point of view of electrical strength corresponds to the main insulation of class 6 kV. Therefore, to protect it from impulse overvoltages, it is necessary to focus on the use of MOA of standard voltage class 6 kV.

When laying cable lines, the cable outer sheath almost always receives some kind of mechanical damage. Because of this, screens bonding/grounding schemes are chosen in such a way that, at short-circuit, the voltage of 50 Hz induced on the screen for a short time does not exceed permissible value of 5-7 kV. This voltage is safe both for the cable outer sheath and for a MOA of class 6 kV, which could withstand it for the entire service life of 30 years.

Currently, mistakes such as the use of a MOA of a voltage class less than 6 kV (for example, class 3 kV), and, in addition, attempts to assign the task not only limiting impulse overvoltages but industrial frequency (50 Hz) voltages too, have become characteristic in choosing the type of MOA.

Mistakes when choosing the type of the MOA

It is impossible to use an MOA of a voltage class of more than 6 kV to protect the cable outer sheath, since the voltage at its terminals during the passage of impulse currents will be higher than the impulse strength of the outer sheath of single-core cable. However, it may seem that reducing the MOA operating voltage, on the contrary, will be useful, since it will better protect the sheath from impulse overvoltages. This is partly why in cable link-boxes of a number of foreign manufacturers there are MOA of voltage class 3 kV, and some domestic design organizations, adopting this "experience", require mentioned MOA 3 kV from domestic manufacturers. As a result, there is a significant number of damages in boxes with MOA 3 kV (see Photos 2, 3).

Damage of the MOA 3 kV occurs for three possible reasons:

– screens bonding/grounding scheme is considered acceptable, in which the voltage on the screen relative to the ground at short-circuit is 5-7 kV, whereas for MOA 3 kV such voltage of 50 Hz is already dangerous and cause damage;
– the lower the operating voltage of the MOA, the deeper it limits impulse overvoltages and, consequently, the more energy impulse currents passing through it; thus, we have a higher risk of MOA damage due to insufficient ability of energy consumption;
– there is an unwritten rule: the lower the operating voltage of a typical MOA, the smaller the diameter of its metal-oxide nonlinear elements and less their ability of withstanding impulse currents; thus, we have a higher risk of MOA damage due to insufficient ability of energy consumption.

The first reason causes damage only when there is a short-circuit in the network, and the second and third lead to the failure of the MOA even with simple switching of the cable under grid voltage without any short-circuits.

Photo 2. The consequences of using a 3 kV MOA in screens end link-box (ELB) of foreign production.

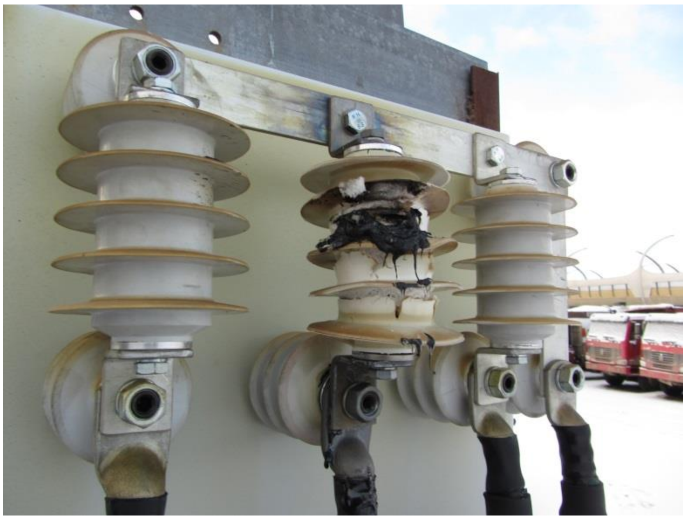

Photo 3. The consequences of using a 3 kV MOA in screens end link-box (ELB) of domestic production.

Mistakes in understanding the purpose of the MOA

There is an opinion that the MOA is installed, among other things, to limit the voltage of the industrial frequency 50 Hz on the cable outer sheath. For instance, we can hear the following chain of reasoning: "For a cable line with screens one-side grounding, the voltage of industrial frequency 50 Hz induced on the screen with an external short-circuit, according to calculations [1, 2], was 15 kV. This is more than the permissible value for the outer sheath of 5-7 kV. Then, by placing MOA of voltage class 6 kV at the end of the cable line between the screen and the ground, it will be possible to reduce overvoltages to a safe level."

The fallacy of the reasoning lies in the fact that the MOA is not designed to limit the voltage of 50 Hz, i.e., the most important condition for the use of the MOA is to ensure that the 50 Hz voltage is permissible for the MOA at the place of its installation. In other words, if, say, a 6 kV MOA is installed in a 15 kV class network, then such MOA will be damaged, and a 15 kV class network will not turn into a 6 kV network.

So, the most important condition for the possibility of protecting the cable line outer sheath from impulse overvoltages due to the installation of a MOA is a competent choice of the screens bonding/grounding scheme, which ensures that the voltage induced on the screen at an industrial frequency (50 Hz) is no more than 5-7 kV at short-circuit.

5. CONCLUSIONS

In 6-500 kV cable lines with single-core cables having screens two-sides grounding, there are noticeable parasitic power losses that limit the cable capacity and require payment. For this reason, simple two-side grounding of screens of single-core cables should be used only if there is an appropriate justification, and preference should be given to screen schemes without parasitic power losses in screens. Among such schemes, screens one-side grounding (for cable lines of short length, no more than several hundred meters) and screens cross-bonding (for all other lengths) have become the most widespread.

1. If it is decided to have screens two-side grounding, then at each of cable line ends three screens must be connected to the grounding circuit in the same place, since this excludes heating of the circuit elements by equalizing currents of the screens.
2. If it is decided to perform one-side grounding of the screens, then schemes with one one-side grounded section should be used, since the separation of the screens of the cable line into several one-side grounded sections complicates the operation of the cable line. In the case when the induced voltage on the screen exceeds the permissible value for the sheath, instead of increasing the number of one-side grounded sections, it is advisable to consider laying a special equipotential conductive bus along the cable line.
3. If a decision is made to perform screens cross-bonding, then one or two complete screen cycles are sufficient for the vast majority of cable lines. Projects with three or more complete cycles or projects where cross-bonding points are performed on each cable joint are highly likely to be erroneous and should be checked and corrected if necessary.
4. Screens cross-bonding scheme remains effective even if it is irregular (different section lengths or laying methods), incomplete (the number of sections is not multiple of three).
5. In cable screens grounding boxes and cross-bonding boxes, the use of MOA of voltage class 3 kV should be prohibited. MOA 6 kV must be installed.

In the next article, we will consider mistakes made when choosing screens grounding boxes, screens cross-bonding boxes, cable joints and connecting wires.

REFERENCES

1. Dmitriev M.V. "Bonding and grounding of power cable screens". -St. Petersburg: Publishing House of Polytechnic university, 2010. -152 p.
2. STO 56947007-29.060.20.103-2011 "Power cables with 110-500 kV insulation made of cross-linked polyethylene. Calculation method of devices for screens bonding, insulation overvoltage protection of insulation".
3. Dmitriev M.V., Kiyatkina M.R. "Metal bus. Efficiency in parallel laying with single-core cables" // "News of Electrical Engineering", No.5(71), 2011, pp.70-73.
4. Dmitriev M.V., Kiyatkina M.R. "Screens cross-bonding for 6-500 kV cable lines. Practical aspects of use" // "News of Electrical Engineering", No.2(74), 2012, pp.80-84.