CABLE SCREEN GROUNDING IN 20 kV NETWORK

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In our country, there are simple methods of choosing optimal grounding schemes for single-core cable screens, the reliability of which has been repeatedly tested in existing 6-500 kV electrical networks and has long been beyond doubt. That's why I would not like to ignore two reports from the materials of the II Conference "Technical and economic aspects of the development of 20 kV electric networks" (Moscow, July 12.07.2016), which were published in "ELECTRICITY: Transmission and Distribution", No. 5(38), 2016.

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Introduction

The articles [1, 2] are mainly devoted to various schemes for grounding cable screens in 20 kV networks, the development of which is a very urgent task for the Moscow and the region. Discussion of these materials is required because they contradict each other. Thus, in [1] it is indicated that a simple two-side grounding of screens is permissible for all 20 kV cable lines, and in [2] readers are inclined rather to perform one-side grounding of screens.

Based on calculations for a 500/16 mm^2 cable, article [1] states that problems with currents and losses in the screens of 20 kV cable lines are far-fetched, and that it is quite acceptable to perform the simplest two-side grounding of screens everywhere. It is difficult to agree with this, since:

– the screen cross section of 16 mm^2 is not produced by cable plants for 500 mm^2 cores;
– the actual distances between the phases of the line are greater than those corresponding to the laying of a closed triangle, for example, because more and more cables are placed phase by phase in polymer pipes with a diameter of 110 to 225 mm each.

In [2], attention is paid not only to losses in screens, but also to a number of other important issues, including potential removal and electrical safety. The conclusions of the article say that for each of the objects it is necessary to carry out calculations and justify the optimal technical solution, but in general preference should be given to one-side grounding of screens. These considerations can only be supported, although the number of connection and grounding schemes considered by the authors [2] is excessive, because most of them, obviously, will never be implemented due to difficulties with the organization of operation. In particular, we are talking about schemes:

– with periodic non-separable combination (connection) of screens with each other;
– with resistors connected between the screens and the ground.

The non-separable combination of screens in cable joints was indeed used for some time in the Moscow cable network, since it was believed that due to the parallel connection of screens, their resistance to short-circuit currents increases. However, then the decision was abandoned, since it is very difficult to organize cable outer sheath damage locating for such lines. Also, in the book [3] it was shown that the combination of screens, contrary to expectations, does not really change the thermal stability of the screens.

If we talk about installing resistors on one of the ends of the screen, then this solution is an "intermediate" option between two-side grounding (resistor resistance is 0) and one-side grounding (resistance is infinity). By selecting the resistance value of the resistor, you can find the best combination of the magnitude of power losses in the screens and the voltage on the screens relative to the ground. This technical solution is not used in the world because of the next reasons. Firstly, in normal operation, an industrial frequency AC current passes through the resistors, there are power losses in resistors, they must be paid for, and the heat released must be removed to the surrounding space. Secondly, with any short circuit of the cable line, significant energy will be released in the resistors, they will "heat up", and after disconnecting the line they will cool down for a long time, clearly preventing the personnel from quickly disconnecting them and starting to locate for the place of damage. Thirdly, the resistors suitable in terms of parameters are dimensional, which in combination with their constant heating causes difficulties with placement in switchgear.

Let's take a closer look at the issues of single-core cable screen grounding for 20 kV cable lines, choosing between the two simplest technical solutions – two-side and one-side grounding. The choice of the optimal scheme, as mentioned in [3, 4], fundamentally depends on two factors:

- screen cross-section;
- the distance between the phases.

Screen cross-section selection

The screen cross-section F_S should ensure that there is no dangerous XLPE insulation overheating when short-circuit (SC) current I_{SC} passes through screen (Fig.1, screen currents I_{S1}, I_{S2}). For networks with large short-circuit currents I_{SC} and/or disconnecting time, cables with large screen cross-sections F_S have to be used. However, in normal operation, such screens, on the contrary, are undesirable, since their two-side grounding will lead to significant induced AC currents and power losses. In other words, short circuits and normal mode have different requirements: in case of accidents, it is better to have a cable with a large screen cross-section F_S, and in normal mode – with a small screen cross-section F_S, which will allow screens to be simply grounded on both sides and not worry about induced currents and their consequences.

It is shown in [3] that of all medium-voltage networks 6-35 kV, only those where a "low-resistance" resistor is installed in the neutral allow to have single-core cables with small screens cross-section and at the same time do not afraid screens overheating by short-circuit currents. Therefore, just for new networks with resistively grounded neutral, to which 20 kV in Moscow belongs, there is a desire to allow two-side grounding of screens, because it does not seem to be accompanied by dangerous screen induced currents and power losses.

Unfortunately, not everything is so simple. The fact is that, although networks with resistive neutral grounding formally allow you to have single-core cables even with screens of only 16 mm^2, which are mentioned in [1], but factories are ready to produce no less than 35 mm^2. Also, the laying of three phases with a closed triangle, mentioned in [1], is hardly possible in practice, because more and more lines receive sections in pipes.

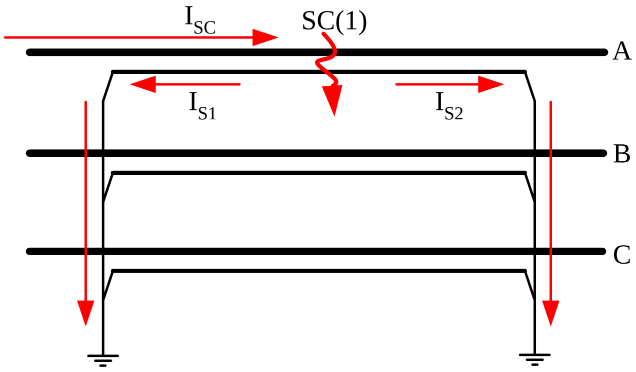

Fig.1. The scheme of simple two-side grounding of screens for line with single-core cables.

Minimum screen cross-section

In factories, there is a minimum cross-section of one screen wire, and only a few such single wires are required to reach 16 mm^2. But several of the mentioned wires will not be able to evenly and tightly cover the insulation surface, providing a uniform electric field inside insulation. In other words, the minimum technologically possible cross-section of the screen is closely related to the circumference over the cable insulation, which is determined by the cross-section of the cable core and the class of its rated voltage (insulation thickness).

Figure 2 schematically shows a single-core cable with different cross-sections of screens. If the screen cross-section was 25 mm^2, then the single wires (red) would be very far from each other, which would not allow us to consider the field inside the insulation uniform. Increasing the screen cross-section from 25 up to 50 mm^2 (red and green wires) already makes it possible to correct the situation, and 95 mm^2 (three colors together) is ideal.

In catalogs, the growth of the cable core cross-sections and the voltage class is always accompanied by an increase in the minimum produced screen cross-section. In particular, 20 kV 500 mm^2 cables are not available with screens less than 35 mm^2.

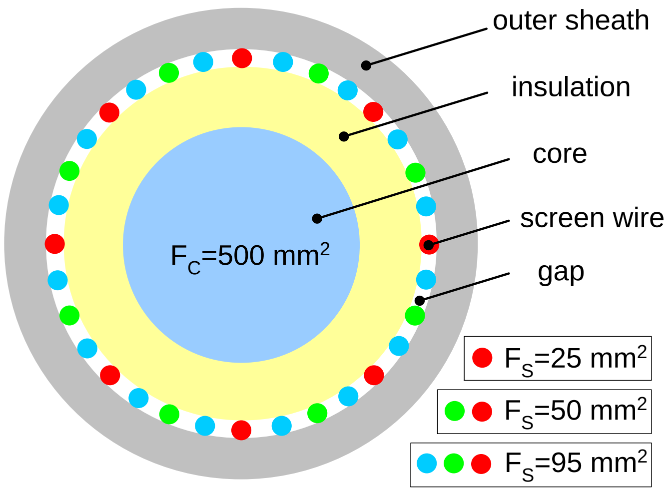

Fig.2. Single-core cable design.

So, unfortunately, there can be no question of a screen cross-section of 16 mm^2 for a 500 mm^2 core, even if such a screen cross-section is sufficient to withstand single-phase insulation fault accompanying by short circuit current (Figure 1) passing through the screens and heating them during the time until relay protection disconnects the line by its switches.

When screens have two-side grounding their cross-section (16, 25, 35, 50, 70, 95, 120, 150 mm^2 and others) significantly affects the screen induced currents and power losses. Therefore, the conclusions made in [1] for $F_S = 16$ mm^2 cannot relate to other "real" cross-sections. This explains why the authors [2], who relied on $F_S = 35$ mm^2 or more, no longer named two-side grounding as the optimal scheme, as in [1], but rather one-side grounding.

Distance between phases

In matters of grounding screens of single-core cables, the most fundamental role is played by the average distance between phases along the route. The lowest induced currents and voltages can be achieved when laying phases close to each other in the form of a closed triangle.

Over the years, approaches to the construction of cable lines are gradually changing, and now it is difficult to find a line where there would be no sections laid in pipes. Most often, the cable phases are laid not in a common pipe, but each in a separate one. This leads to an increase in the distance between the phases of the cable in the pipe sections, and hence to an increase in the average distance along the route. Figure 3 shows as an example a route where the phases lie in pipes in the middle part.

A single-core cable of voltage class 20 kV with a core cross-section of 500 mm^2 has an outer diameter of about 50 mm and can be placed in a pipe with a diameter of 110 mm:

– when laying the entire route without pipes, just in the ground with a closed triangle, the distance between the axes of the phases is equal to the cable diameter of 50 mm;
– when laying the entire route in pipes located close to each other in a triangle, the distance between the axes of the phases is equal to the pipe diameter of 110 mm;
– if, for example, only half of the route is in the pipes, then the average distance along the route will be $(50 + 110)/2 = 80$ mm.

As can be seen, the average distance between phases depends on the relative length of the route where the phases are laid in pipes, as well as on the diameter of these pipes and their placement to each other. Let's give an example of the calculation.

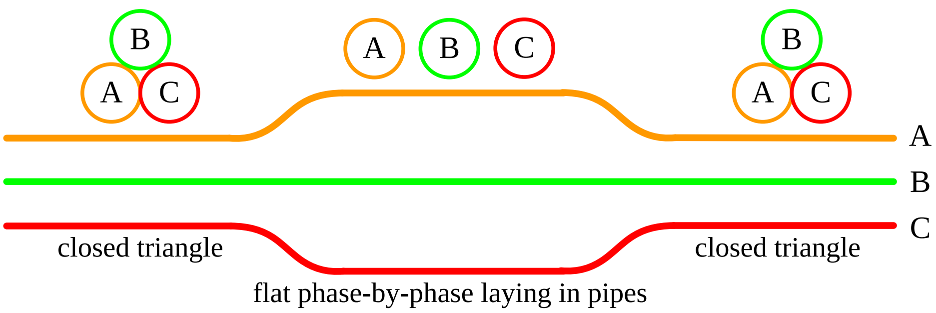

Fig.3. Example of changing the relative position of phases along the line route.

Calculation example for 20 kV cable

Figure 4 shows the results of calculating the ratio of power losses in the screen P_S and in the core P_C for a 20 kV line made with single-core cables of $F_C = 500$ mm². The screens have two-side grounding, and their cross-section varies in the range from $F_S = 16$ mm² up to 120 mm². The core material is either copper or aluminum. The length of the cable line is not specified because it does not affect P_S/P_C.

Three variants of the line route were considered in the calculations:

– the whole route is a closed triangle without pipes;
– one or another percentage of the route is laid in pipes with 110 mm diameter, arranged in a triangle close to each other (for example, "25% in pipes" means that 25% of the route is laid in pipes, and 75% – in the ground in a closed triangle);
– the entire route is in a row with a distance between phase axes equal 110 mm (this can be either a laying in the open ground with a specified distance, or a laying in 110 mm pipes, which are laid in a row close to each other).

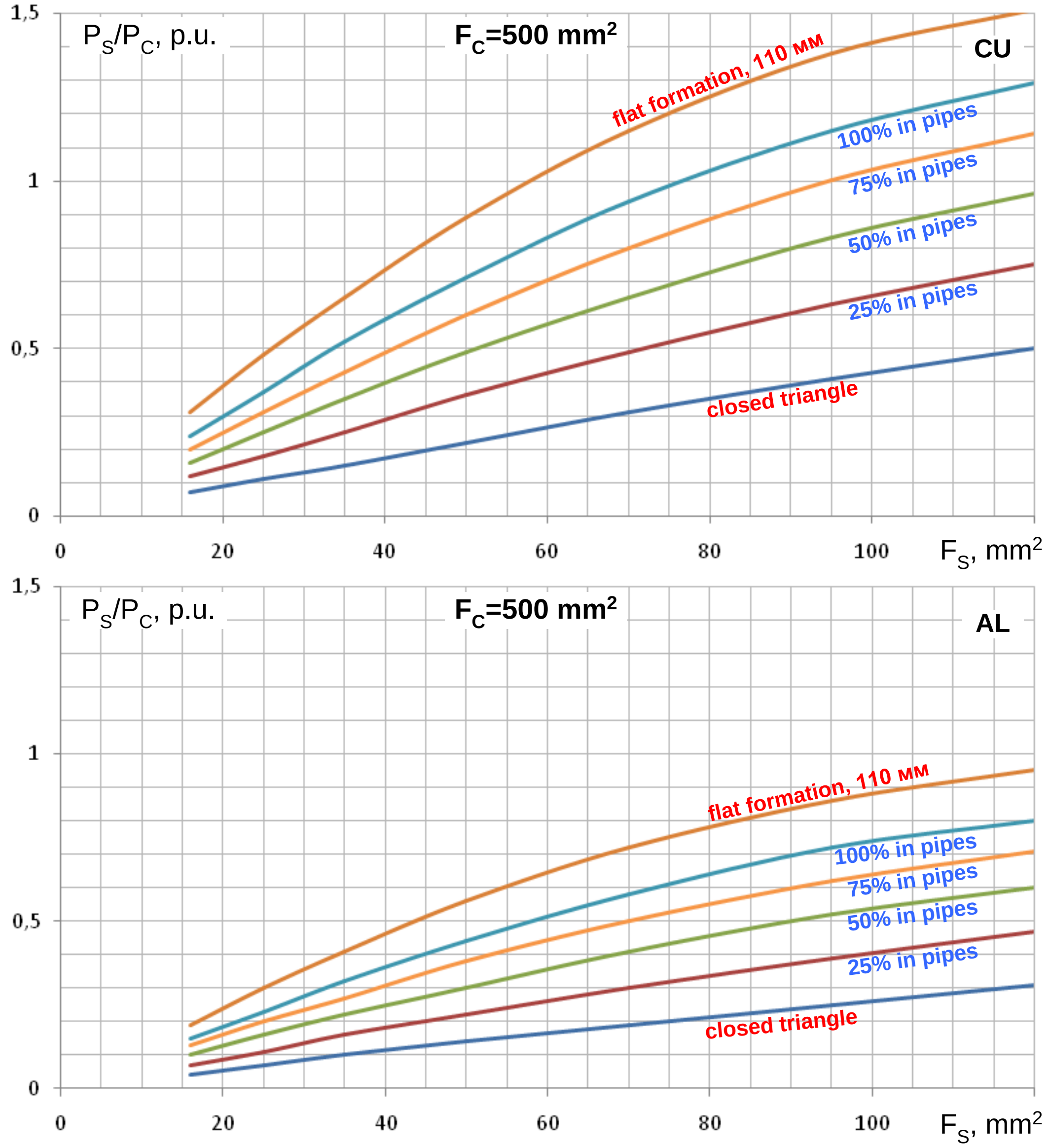

Fig.4. Relative losses in both-side grounded 20 kV cable screens with a copper (CU) or aluminum (AL) core cross-section of 500 mm², depending on the relative position of the phases.

With two-side grounding of screens, the ratio $P_S/P_C > 0$ shows the role of losses in the screen against the background of losses in the core and allows us to assess the feasibility of abandoning two-side grounding in favor of one-side grounding or screens cross-bonding (for both of these options, $P_S/P_C = 0$ is valid).

Figure 4 shows that for triangle-laid cables with screens up to 35 mm^2, $P_S/P_C \leq 0.2$ is true, that is, the losses in the screens are no more than 20% of the losses in the cores. If part of the cable line route is located in pipes, the losses increase to $P_S/P_C \leq 0.5$. For screen sections over 35 mm^2, the ratio P_S/P_C becomes even worse.

In addition to the relative losses in the P_S/P_C screens, there is another important indicator – this is the cable current capacity utilization factor

$$K_U = \frac{1}{\sqrt{1 + P_S/P_C}}$$

which shows how much cable current capacity is relative to the value, obtained without any screen power losses due to induced currents:

– for $P_S/P_C = 0.5$ we have $K_U \approx 0.8$;
– for $P_S/P_C = 0.2$ we have $K_U \approx 0.9$;
– for $P_S/P_C = 0$ we have $K_U = 1$.

These figures mean that the purchased cable can be used for no more than 80% or 90% of its catalog current capacity, obtained without taking into account the presence of parasitic currents and power losses in the screens. The loss of 20% or even only 10% of the current capacity of an expensive cable is unlikely to please anyone, and for this reason, for many 20 kV cable lines, it is advisable to combat currents and power losses in the screens. The most knows ways are screens one-side grounding or screens cross-bonding.

To make a decision on the optimal grounding scheme, in addition to the values P_S/P_C and K_U that do not depend on the length of the line, it is necessary to estimate the annual (during 1 year) cost of power losses in the screens C_{1Y}, which is already directly proportional to this length. For example, in [4] it is shown that the annual cost of losses in the screens of three phases of a 6 km long line having $P_S/P_C \approx 0.4$ reached 10 thousand euro, and over the service life the cost from losses in the screens would amount up to 0.5 million euro.

So, the proposal of the authors [1] to allow simple two-side grounding of screens everywhere in 20 kV networks is not entirely correct, since such an idea is based on the value P_S/P_C obtained only for a small screen cross-section and a small distance between phases, without any analysis of the annual cost of power losses in screens C_{1Y}, depending on the length lines.

Conclusions

The reasoning showed that in 20 kV networks, even if they have a resistive neutral and a small cable screen cross-section, the choice of the optimal screens grounding scheme remains a problem, when solving which it is necessary to take into account factors such as the average distance between phases along the line and the overall length of the route.

The calculation of currents, voltages, and power losses in the screens of single-core 6-500 kV cables has been and remains an important section of the project documentation.

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