Semiconductive layer over the cable sheath. Problems and possible solutions

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***Abstract* —** *Modern cross-linked polyethylene insulated cables play a key role in the energy system and are widely used in both medium-voltage 6-35 kV and high-voltage 110-500 kV networks. For some applications, the outer sheath of cables is covered with a thin semi-conductive layer, which makes it easier to detect damage to the sheath. This is important, to ensure that the cable has not lost its tightness and water does not penetrate it. Unfortunately, operational experience has shown that under certain circumstances, a semiconductive layer can not only benefit a cable, but also significantly harm it. The article analyses some of these cases.*

Keywords: *cable line, single-core cable, XLPE insulation, cable outer sheath, semiconductive layer over the cable, cable sheath testing, sheath damage.*

I. INTRODUCTION

The design of modern cables can include a variety of elements, depending on the intended field of its application. However, perhaps no cable with a voltage class of more than 1 kV can do without a conductor, insulation, a metal screen on top of the insulation, and an outer sheath [1-4]. Although the metal screen and the outer sheath, unlike the conductor and insulation, seem to be minor structural elements, in fact they perform important functions: the grounded screen is responsible for equalizing the electric field in the insulation (and for some additional functions), and the outer sheath allows sealing the cable, i.e. protect it from moisture penetration (water is dangerous for the insulation and can sooner or later lead to its breakdown).

The condition of the cable outer sheath is checked by testing, in which voltage is applied between a temporarily ungrounded metal screen and the ground, and if current is detected in this circuit, this is interpreted as damage to the cable outer sheath.

The problem is that there are cases where current cannot flow in the circuit, even if there is a damaged outer sheath. For example, such cases include the following options of cable laying:

- in dry soil;
- on open structures (overpass, bridge, tunnel etc.);
- in polymer pipes/ducts/conduits.

The listed options are quite common, and to ensure the possibility of objective testing of the cable outer sheath, it may be covered with a thin semiconductive (SC) layer with a thickness of at least 0.1 mm. This SC layer is mentioned in [1-4] and can be sprayed onto the sheath, but more often it is extruded together with the main dielectric sheath of the cable.

In accordance with the technical policy of grid companies, 110-500 kV high-voltage cables are often manufactured with an outer sheath equipped with a SC layer, and for 6-35 kV cables, due to their lower responsibility, the use of a SC layer is not so common. A SC layer over the cable sheath is usually considered as an advantage of the cable, and the presence of such a layer leads to a certain increase in the cost of the cable, which is paid by the customer.

In this regard, it is interesting to note that, according to collected operational experience, under certain circumstances that are not reflected in regulatory documents, the SC layer over the sheath can cause serious damage to the cable. We are talking about cases where there is only a limited number of places along the route of the cable line where the SC layer is in contact with the "ground" (soil or grounded structures), and damage to the cable is likely in these places.

To show this, we will consider three different situations:

1) Cable sheath testing and damage locating.
2) Energizing the cable line.
3) Normal operation of the cable line.

II. OUTER SHEATH TESTING

The cable outer sheath tests are carried out both in the factory right after the extrusion of the sheath ("pass-through" tests), and later at the facility, after the cable is delivered and laid. According to chapter 5 of [5], for cables of 110-500 kV classes (their sheath thickness is usually about 4-5 mm), for the electrical test after installation it is required that the sheath is checked by applying a DC test voltage of $U_T = 10$ kV for a period of 1 min. Voltage is applied between the ungrounded screen and the ground, as shown in Fig.1.

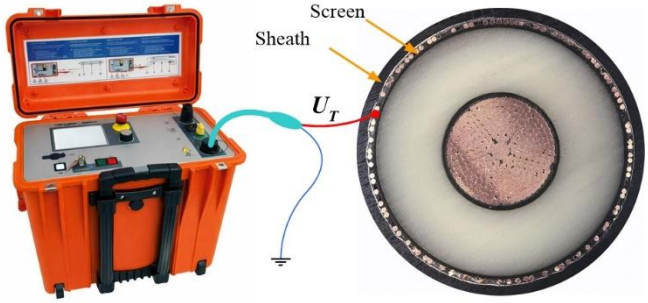


Fig.1. Cable sheath testing diagram.

If the cable sheath has a SC layer, then it is possible to apply voltage between the screen and this SC layer (and not the ground). For example, in this way it is possible to test the sheath of a cable that is located on a cable drum. However, when testing a laid cable, it is not always advantageous to apply test voltage between the screen and the SC layer. The fact is that at the installation sites of the cable couplings (terminations and joints), SC layer is removed from the outer sheath, and thereby many SC layer breaks appear along the cable line, which means that the test voltage U_T between the

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screen and the SC layer applied at the beginning of the cable cannot be transmitted to subsequent cable sections located behind the cable joints. It should be noted, that in cases where the project provides for filling the joints with soil, after such a filling, breaks of the SC layer are shunted by soil, and there should be no interference with the sheath tests.

Removing the SC layer from the sheath when installing cable couplings is necessary in order to ensure a gap between the metal screen of the cable and the SC layer of the sheath. If the gap between the two specified elements (the screen and the SC layer) is missing or insufficient, then when testing the sheath, a breakdown will occur from the screen to the SC layer and further to the ground, which will shunt the cable sheath and prevent an objective assessment of its condition. Thus, when installing each cable coupling (termination or joint), it is necessary to remove a SC layer from the cable sheath on a section of several centimeters long, as indicated in the instructions for installing the couplings.

Sometimes the gap of the SC layer is organized not inside the coupling, but outside it. This is done in order to enable a visual inspection of the coupling and check for a gap in the SC layer. An example of such a coupling (cable termination) is shown in Fig.2, where the black outer SC layer has been removed, and the main part of the outer sheath, which has a natural colour, is visible under it ("natural colour" means that the main part of the outer sheath is white, without colouring).

In some cases, cable factories can produce the cable outer sheath not in natural (white) colour, but in red, which is also convenient for monitoring the removal of the SC layer. If the outer sheath of the cable and the SC layer are both made of the same colour (say black), then visually (as in Fig.2) it will no longer be possible to verify that the SC layer has been removed.



Fig.2. Visible gap of the SC layer on the cable outer sheath.

Let us consider further the features of testing the sheath. Assume that a test voltage U_T is applied to the ungrounded screen of the cable (Fig.3). If the cable sheath is damaged, and the cable in this place has good contact with the "ground" (soil or with some grounded structures on which it is laid), then a current will pass under the action of voltage U_T (Fig.3a), and the fact of the presence of current means that the cable sheath is damaged, and it will be required:

- search for a damage location (items 2.3-2.4 of [6]);
- repair the damaged sheath;
- repeat tests of the sheath.

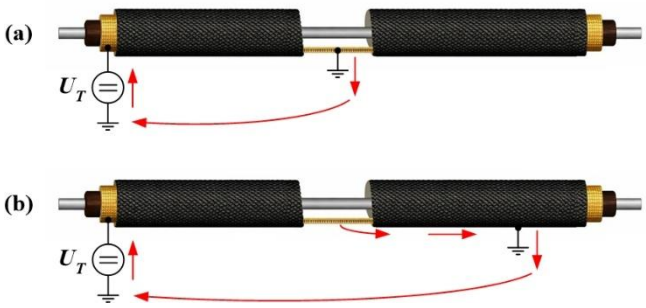


Fig.3. Places where the test current flows to the ground:
(a) – directly at the site of sheath damage;
(b) – in a place where the SC layer is in a contact with the ground.

In practice, there may be situations where there is no contact with the "ground" (soil or grounded structures) at the point of damage to the cable sheath. For example, this can be either in the case of cable lying in dry soil, or in the air, or in polymer pipes. In all these cases, the SC layer can increase the probability of detecting a damage, but it is still extremely important that such an SC layer has a good contact with the "ground", even if not directly at the site of the sheath damage, but somewhere else along the cable route (Fig.3b). If the SC layer has few points of contact with the "ground" (or has no contact at all) then its effectiveness decreases (or disappears).

In a situation where the SC layer has few places of contact with the "ground", another problem arises – in these places the current is concentrated, flowing from the surface of the cable into the "ground" (soil or grounded structures), creating a threat of local point overheating of the sheath, its melting and even damage. This can happen, for example, during the procedure of locating for a site of the sheath damage, because depending on the method/device used for locating, the current can reach tens of Amperes (the nature of the locating current varies between impulse, direct, and alternating).

In particular, this situation occurs when laying cables in polymer pipes, which are usually dielectric and therefore release current from the SC layer of the cable into the ground only at the ends of the pipe section. This not only creates risks for the SC layer and the outer sheath in places where the test current is concentrated, but is also generally useless for localizing damage along the pipe section (when locating for a damage, the fact that current is released into the ground at the ends of the pipe section does not give an idea of exactly where the cable sheath damage is located on the pipe section). Thus, the more contact points the SC layer has with the ground in the pipe sections, the safer it is for the SC layer (and the cable sheath), and the easier and more accurate it is to find the original damage site.

III. SWITCHING OF THE CABLE LINE

Problems that arise in places of poor contact of the SC layer of the outer sheath with the "ground" (soil or grounded structures) manifest themselves not only during testing and damage locating, but also during switching of the cable line [7] and during its normal operation.

As an example, consider switching on a 220 kV cable line, during which the photo (Fig.4) taken from video depicts numerous arc flashovers occurring at the cable attachment points to the supporting metal structures. This 220 kV cable line feeds the 220 kV power transformer and is connected to it by so-called "cable adapters". The flashovers (discharges, sparks) occurred through the air, between the SC layer of the cable outer sheath and the aluminium cleats fixing the cable to grounded metal structures, and represented discharges in the air of silicone inserts between the cable and the cleats (Fig.5a), accompanied by loud claps.

Flashovers (sparks) are caused by short voltage impulses induced on the SC layer of the sheath during switching of the line. According to the modelling of processes in software [8], similar to what was done in [9] for voltage induced on screen, the peak values of voltage on SC layer were up to 2 kV.

The situation is dangerous because these sparks occur each time at the same places of the outer sheath, gradually destroying it.

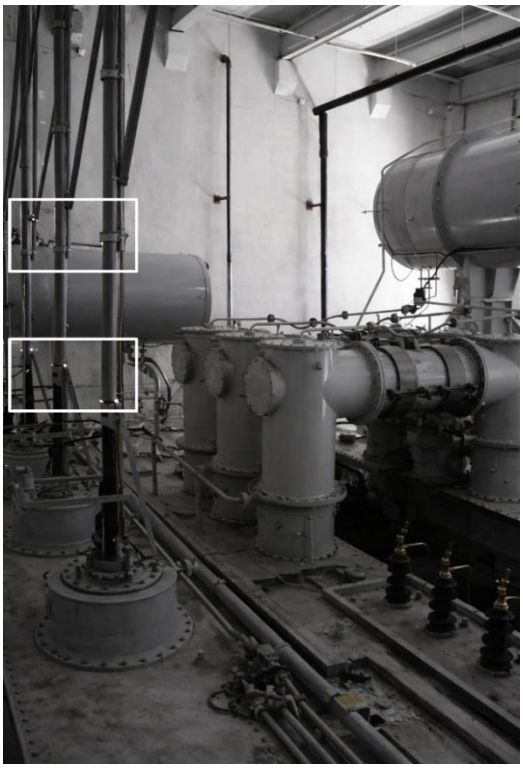


Fig.4. Sparking when switching on the 220 kV cable line.

The elimination of flashovers could be achieved in one of two ways:

1) Significantly increase the number of contact points of the SC layer with the "ground", i.e. abandon silicone inserts with dielectric properties;
2) Completely eliminate any contact of the SC layer with the "ground", i.e. strengthen the insulation at the points where the cables are attached to the metal structures.

Since it was not possible to abandon silicone inserts (they protect the cable outer sheath from mechanical damage), the second method was chosen to solve the problem – personnel replaced aluminium cleats with polyamide (Fig.5b), which ensured a higher level of insulation of the SC layer from the "ground" and completely eliminated the problem of sparks (flashovers, loud claps) in the cleats, eliminating cable outer sheath degradation. Complete ungrounding of the SC layer over the cable turned out to be the optimal solution, among other things, because due to the peculiarities of the cable line route, there was no possibility of personnel touching the cable surface both at the time of line switching and during normal operation.

In general, impulse flashovers (sparks) from the SC layer to the "ground" can occur not only in the case of laying cables on structures, but also when laying cables in dry soil or in polymer pipes. For example, if a significant part of the cable line route is located in dielectric polymer pipes, then point flashovers from the SC layer to the soil can be expected at the ends of the pipe sections. However, unlike an open-air laying, it will be impossible to notice such negative processes in time, and serious damage will not be avoided – as it happened in the case described below.

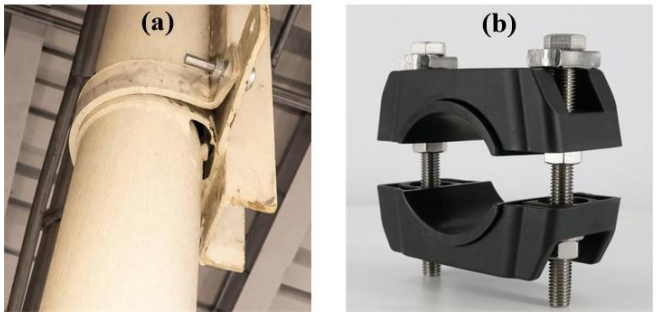


Fig.5. Standard cable cleats:
(a) – aluminium with silicone insert;
(b) – polyamide (dielectric).

IV. NORMAL OPERATION OF THE CABLE LINE

Degradation of the SC-coated outer sheath can occur not only during cable testing or switching, but also during normal operation. Let us show this, for example, by referring to the case of one of the high-voltage cable lines.

Three single-core cables of a 132 kV line were laid in the ground in three (phases A, B, C) separate corrugated polymer pipes. After completing the planned cable outer sheath tests, the personnel mistakenly did not return the grounding of the metal screens to the condition planned by design. As a result, after switching on the power supply, the cables of this 132 kV line were exposed to AC 50 Hz grid voltage, for several days, without having any grounding of the screens.

Accordingly, there was an AC 50 Hz voltage of 15 kV on the metal screen of each cable (due to the capacitive coupling between the cable conductor and the screen). In turn, under the influence of the specified AC voltage, a capacitive current passed from the screen through the outer sheath to the ground. Since the cable line was laid in dielectric pipes, the current could not evenly escape from cable into the ground (using the entire length of the cable for this), but concentrated only in the place where the SC layer was in a good contact with the "ground".

The flow of the current from the SC layer into the ground turned out to be the concentrated at the point of connection of two adjacent pipe sections made by a plastic coupler (Fig.6). Such a plastic coupler, firstly, has reduced electrical strength compared to the pipe itself, and secondly, it cannot provide for pipe sealing (cannot stop water penetration into the pipe). Both factors led to the leakage of AC 50 Hz current from the SC layer of the cable sheath into the ground at this particular point of the route of the line. Since AC 50 Hz current flowed continuously for several days, the cable sheath was damaged (Fig.7) and required major repairs.



Fig.6. Plastic coupler connecting two dielectric polymer pipes.



Fig.7. Consequences of the point contact of the SC layer with the ground at the pipe junction.

Of course, the screens must be grounded according to the design before switching on the line. This is an important rule, but in practice there are still a lot of cases when the cable line is switched on without proper grounding of the screens.

If the cable outer sheath did not have a SC layer at all, then the fact that the screens were not grounded would not cause any damage to the sheath, since the AC 50 Hz voltage on the ungrounded metal screen (it can be up to 15 kV) would not be sufficient to break the sheath of a good condition.

If we consider a cable with a SC layer, then avoiding such serious damage to the sheath (Fig.7) could be achieved in one of the following ways:

1) Significantly increase the number of contact points of the SC layer with the "ground", i.e. lay the cable either directly in the ground or in conductive pipes;
2) Completely eliminate any contact of the SC layer with the "ground".

The second option is hardly possible when laying cables in the ground (soil). As for the first option, then laying cables in pipes is advantageous for many sections of the line, and therefore for such sections, in order to avoid point damage to the outer sheath of the cable, it is necessary to lay cables not in dielectric pipes, but in conductive ones – such pipes can be either metal (made of non-magnetic materials) or polymer, having conductive properties of the side wall, in the direction from the inner surface of the pipe to its outer surface [9].

The use of dielectric pipes equipped with an internal semiconductive layer, proposed in paragraph 3.3.6 of the CIGRE technical brochure [10], does not solve the problem of damages to SC layer over cable sheath, since the problem is not that the pipe does not have longitudinal conductivity, but that the pipe lacks radial conductivity (through the side wall, from inside to outside). Such a radial conductivity of the polymer pipe can be achieved in various ways (it can be a semi-conductive material or separate conductive elements). The resulting pipe wall resistance should not exceed 100 kΩ, to achieve sufficient current at a DC test voltage of 10 kV.

V. CONCLUSIONS

Usually, the technical policy assumes that cables of 110-500 kV classes should have a semiconductive (SC) layer on the cable outer sheath, in order to increase the observability of the condition of this outer sheath. However, according to the operational experience, under certain conditions, the SC layer can pose a danger to cables and network personnel.

The article considers a number of real examples showing that if there are only a limited number of contact points along the cable between the SC layer of the sheath and the "ground" (soil or grounded structures), then spark and arc processes may occur in these places, which can seriously damage the outer sheath of the cable.

When laying cables in the ground (soil), the problem with the SC layer occurs only in the pipe sections, and to solve it, it is enough that the side wall of the pipe can conduct current from inside to outside. The use of dielectric pipes for laying cables with SC layer is not recommended.

When laying cables in the air (tunnels, overpasses, bridges etc.), it is difficult to find any universal solution to the problem, since one has to choose between repeatedly re-grounding the sheath's SC layer or, conversely, completely isolating it from the metal structures on which the cable is laid. The first is difficult due to the lack of appropriate cable cleats on the market, and the second is due to the danger to personnel near the cable. Perhaps, in order to ensure the safety of people, it would be preferable to develop and implement polymer cleats with (semi) conductive properties.

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