XLPE Cables with Aluminium Laminated Sheath

Jens Kristian **LERVIK**, Kristian Thinn **SOLHEIM;** SINTEF Energy Research, Norway, jens.lervik@sintef.no, kristian.solheim@sintef.no

Ketil **KVAALE**, Gunnar **SNARTELAND**; Vest-Telemark Kraftlag AS, Norway, ketil.kvaale@vtk.no, gunnar.snarteland@vtk.no

ABSTRACT

Single-core power cables with aluminium laminate used as radial watertight need qualified solutions and instructions regarding grounding. There is often lack of information from the cable suppliers regarding the importance of proper connections and use of sufficient cross section of grounding wires. The aluminium laminate must be considered as a conducting screen together with the copper wire screen. If the copper screen and laminate are not properly connected at cable joints, end terminations, grounding points etc. cable failure can occur due to heat development caused by induced currents in the screens. Instructions in standards states that any conducting element shall be grounded.

KEYWORDS

XLPE, aluminium laminate, sheath, copper screen, grounding

INTRODUCTION

XLPE power cables with aluminium laminated sheath (laminate) was developed to improve the long term wet ageing performance of power cables and has been in use for about 25 years. The cable suppliers offer these cables in all installations and they are therefore commonly used even in indoor installations of no humid environment. Operational experiences from power utilities and producers on single core cables have not been as good as expected since several faults (insulation breakdown) have occurred. The problems have been related to overheating due to large heat development by capacitive and induced currents in the laminate and copper screen. The main reason of the fault is due to poor performance of the contact between these two elements. The faults occur mainly close to cable joints and at the end terminations, but may also occur close to cable straps where the cable is compressed and the copper screen may be in contact with the laminate. Essential information why and how to carry out the screen terminations may not always be sufficiently emphasized. Fig. 1 shows a sketch of a power cable with laminate.

Preliminary theoretical studies and laboratory tests have been carried out in order to give basis for determining the currents and generated heat in the laminate and copper screen. This is carried out on alternative configurations (trefoil and flat formation) with different cross sections of cable conductor, laminate and copper screen during normal operation and fault conditions (short circuit and ground fault). For installed cable systems where there are uncertainties whether the laminate grounding is properly implemented, analyses are required to decide if the cable systems must be replaced or could be repaired. This is due to the risk of damaged cables. Regarding planned installations it should be evaluated if the watertight design with laminated sheath is needed. Alternative solutions by use of three core cables may in some cases be more reliable if watertight cables are required. In case of repair it should be evaluated if surge arresters for protection against atmospheric and switching over voltages should be used, especially if single point grounding screens are used.

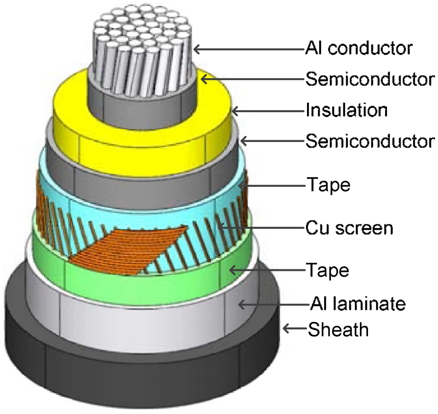

Fig. 1: XLPE power cable with aluminium laminate.

MANUFACTURER' RECOMMENDATIONS

The manufacturer' data sheets do not always give sufficient information of the laminate and cobber screen cross section. The copper screen may be specified as e.g. 35 mm^2 for a 12 kV cable with 240 mm^2 cross section, but the laminate (typical 0,2 mm thick) may also be included giving a reduced copper screen cross section. This implies that the effective equivalent copper screen cross section e.g. is 25 mm^2 and equivalent laminate copper cross section is 10 mm^2. The problem is that the manufacturers do not give any requirement of connecting the copper wire screen and laminate together where the laminate is terminated (at the joints, end terminations etc.). However, this may be very unclearly expressed as "if necessary the laminate and copper screen may be connected".

In addition the instructions of laminate termination may be insufficient as it may not contain recommended and qualified methods. Due to the confusion with the laminate, the practice has often to let the laminate be open.

INDUCED VOLTAGE AND CURRENTS IN SCREENS WITH LAMINATE OPEN

Voltage is induced in the laminates and copper screens from magnetic fields due the conductor currents. If these elements are grounded at both ends, currents are induced. The ratio between the induced voltage and the sum of the grounding and the elements resistances gives a good approximation of the induced currents. This is valid for power cables used in distribution network.

With laminate open the calculation of induced currents is uncertain. The induced voltage in laminate will be the same as for the copper screen. The induced current in the laminate depends on laminate conductance and the conductance between laminate and copper screen since the connection to ground is via the copper screen.

There are different designs using continuous taping between the copper screen and laminate, discontinues taping and no taping. The last two designs give metallic contact between the copper screen and laminate. The taping may consist of swelling and semiconducting tapes and has some conductance. Hence, current will be induced in the laminate even if there is no metallic contact between the laminate and copper screen. For open laminate there will be a current transfer zone at the termination ends. The length of this zone depends on the conductance between the copper screen and laminate. The length will be largest with a continuous taping between the copper screen and laminate and smallest in case of no taping.

Measurements have been carried out on two different fabricates of 12 kV XLPE insulated cabled with an aluminium conductor cross section of 240 mm^2. Table 1 gives cross sections of the copper screen and the laminate, and also the measured conductance between the copper screen and laminate. As seen from the result in Table 1, it is a factor of 10 between the conductances of the tape layer for the two fabricates.

Table 1: Data for the two cable fabricates

Fabricate no.	1	2
Copper screen cross section	20 mm^2	35 mm^2
Laminate equivalent copper conductor cross section	10 mm^2	10 mm^2
Conductance between the layers	0.1 /(Ωm)	1 /(Ωm)

When assuming constant conductance of the tape layer, the current distribution between the copper screen and aluminium laminate is determined by:

$$-dI_{Al} = dI_{Cu} = (V_{Al} - V_{Cu}) \cdot G \cdot dx \qquad [1]$$

$$I_{Al} + I_{Cu} = I \qquad [2]$$

$$E_{Al} = r_{Al} \cdot I_{Al} \qquad [3]$$

$$E_{Cu} = r_{Cu} \cdot I_{Cu} \qquad [4]$$

Solution:

$$I_{Al}(x) \approx \frac{r_{Cu}}{r_{Al} + R_{Cu}} \cdot I - \frac{r_{Cu}}{R_{Al} + R_{Cu}} \cdot I \cdot \frac{\sinh(K \cdot x)}{\sinh\left(K \cdot \frac{L}{2}\right)} \qquad [5]$$

$$K = \sqrt{(r_{Al} + r_{Cu}) \cdot G} \qquad [6]$$

I	Total current.
$I_{Al}(x)$	Current in aluminium laminate.
$I_{Cu}(x)$	Current in copper screen.
$V_{Al}(x)$	Potential in aluminium laminate.
$V_{Cu}(x)$	Potential in copper screen.
$r_{Al}(x)$	Resistance per length in aluminium laminate.
$r_{Cu}(x)$	Resistance per length in copper screen.
G	Conductance per length for the tape layer (wrapping) between aluminium laminate and copper screen.
x	Position along cable, calculated from cable end.

The results of the computed current distribution along the cable for the two fabricates is shown in Fig. 2. At position "0 m" the copper wire screen is grounded and the laminate is cut off and not connected to the copper screen. The tape layer between laminate and copper screen is homogeneous.

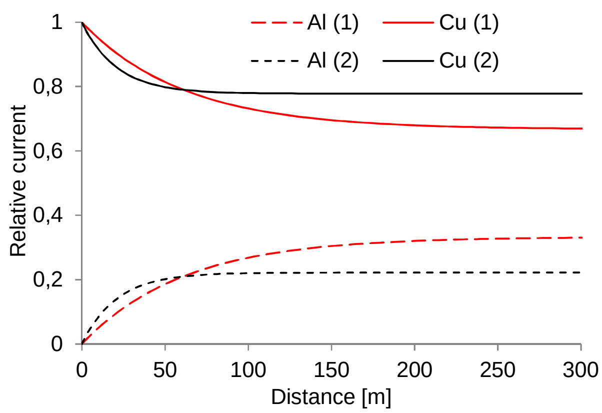

Fig. 2: Relative current distribution in laminate (Al) and copper screen (Cu) for the two fabricates no. 1 and no. 2.

Al (1) and Cu (1) are the relative values of the total screen currents for laminate and copper screen for fabricate no. 1. Al (2) and Cu (2) give the values for fabricate no. 2. As seen the current transfer zone is approximately 200 m for fabricate no. 1 and 50 m for fabricate no. 2. The steady state current distribution (300 m from the termination end) shows that the current in the laminate is 0.33 and 0.67 in the copper screen for fabricate no. 1. The corresponding values for fabricate no. 2 are 0.22 and 0.78 respectively.

Outside the current transfer zone there is insignificant voltage difference between the laminate and copper screen and no current will be transferred from the laminate to the copper screen at this position even if there is a metallic contact (due to rupture of the of the tape layer).

As long as the conductance between the copper screen and laminate is constant along the length the current will be transferred frequently via the copper screen to ground in the current transfer zone. In the current transfer zone a metallic contact may cause overheating in case a large part of the current in the laminate is transferred via one or a few copper wires. If there are several damages of the tape layer, overheating can happen at several locations over time. Possible locations can be close to cable straps/cleats where the laminate wires may be squeezed into the copper screen.

The risk of failure will be highest for cable runs with the highest induced currents in the screens. For trefoil configurations the induced currents are considerably less than for cables in flat formation. The screen current increase when the distance between the cables increases. Cables of large cross sections will in general have the highest induced currents in the screens due to higher conductor currents, larger cross sections of screens and increased distance.

It is expected that the designs with direct metallic contact between copper screen and laminate have considerable smaller current transfer zone than for the case considered in Fig. 2. Even for the "direct metallic contact" designs there is a risk for overheating due to that some few contacts points may have considerably lower contact resistance compared to the others. Possible fault locations for these designs may also be close to cable straps/cleats where the laminate may be squeezed into the copper screen wires.

Fig. 3 shows sheath damages of a power cable installation near a termination end. In this case, the laminate and copper screen were not terminated at the ends. The marked locations in the figure indicate melting of the outer sheath due high power dissipation in random connections between laminate and copper screen. Fig. 4 shows a detailed failure from this installation. A study of joint failure is given in [1] considering assessment of overheating service aged XLPE joints by partial discharge measurements.

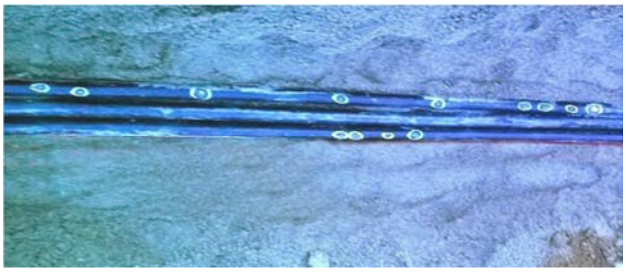

Fig. 3: Multiple damages in power cable sheath close to end termination. Laminate and copper screen not connected.

Fig. 4: Detailed damage from installation in Fig. 3.

EXAMPLES OF COMPUTED INDUCED CURRENTS AND VOLTAGES

The normal practise according to regulations for electrical installations is grounding of screens in both ends. The induced currents lead to power loss and contribute to raise the cable temperature. Screen currents can be avoided (reducing the power losses) by cross bonding of cable screen or grounding the screens at one end only (open screens).

In case of cross bonding and single point grounding the induced screen voltages shall be computed and is accepted if general measures is taken related to HSE. The induced voltages shall not exceed the voltage limit of the cable sheath. In addition to normal operation (symmetrical current load) it is recommended to consider:

- induced voltage during short circuit and ground fault conditions.
- voltage build up due to transients related to switching and lightening.

In case of open screens it may be necessary with surge arresters. These are common available for a wide voltage range.

Reference [2] considers a cable system where faults occurred at several locations after short time of operation. The faults were caused by high heat development due to accidental contacts between laminate and copper screen wires. In this case the laminate and copper screen were not properly connected at joints and terminations. After replacement of several cable sections, connecting the laminate and copper screen properly at every joint and end termination, it was decided to ground the screens at one end only. No faults have occurred after repair. In this case, it was possible to leave the screen open instead of replace the entire cable, saving huge costs.

The induced currents and voltage in screens depend on the configuration, applied currents, cross sections of the conducting elements, temperature, grounding resistances etc. Trefoil formations give in general less induced currents and voltage in the cable screens compared to flat formation. According to IEC 60287 the current rating for trefoil and flat formation for cables in ground is almost equal for screens grounded in both ends. Two single core cable cross sections (12 kV 3x1x400mm^2 and 66 kV 3x1x1000mm^2) both with conductor of aluminum are selected to illustrate effect of screen currents for trefoil and flat formation. Both cables have an aluminum laminate of 0.2 mm thickness. The cross section of the copper wire screen for the 12 kV cable is 35 mm^2 and 50 mm^2 for the 66 kV cable. The computations are carried out by finite element tools [3, 4] on the flat and trefoil configurations shown in Fig. 5 buried at a depth of 1 m.

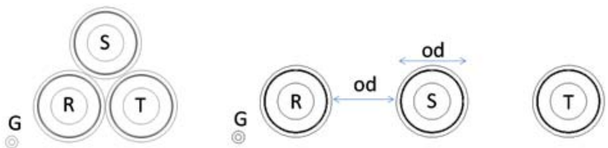

Fig. 5: Studied examples - trefoil and flat formation in ground at 1 m depth. G is the ground wire. The air gap between the cables is equal to the cable outer diameter.

The results from computations are shown in the temperature plot in Fig. 6 at a current of 400 A with cables of 12 kV and aluminum conductor cross section of 400 mm^2 for the case with grounded screens at both ends. The maximum temperature is 61℃ for both flat and trefoil configuration. With the open screens the maximum temperature is reduced to 50℃ for the flat configuration and to 58℃ for the trefoil configuration, see temperature plot in Fig. 6. Corresponding calculations are carried out for the 66 kV and aluminum conductor cross section of 1000 mm^2. Fig. 7 shows the results. As seen from the results the temperature is more reduced for the flat formation compared to the trefoil.

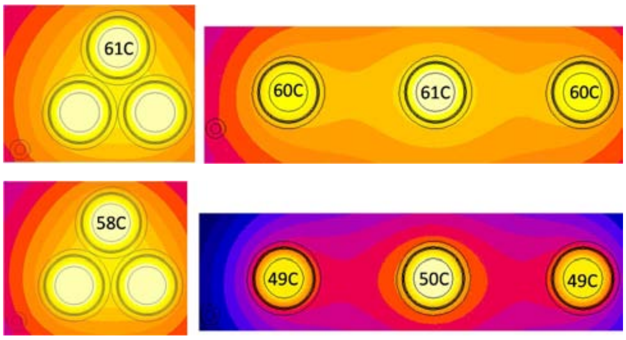

Fig. 6: Maximum temperatures for the cables of 12 kV and 400 mm^2 at 400 A buried 1 m. Upper case with grounded screen, lower case with open.

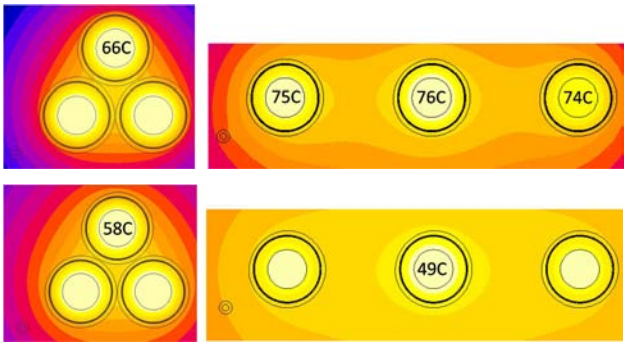

Fig. 7: Maximum temperatures for the cables of 66 kV and 1000 mm^2 at 600 A buried 1 m. Upper case with grounded screen, lower case with open.

The total power loss for each of the configurations in Figs. 6 - 7 and induced currents in the laminate and copper screen are shown in Tables 2-3 for the two cable dimensions. Induced voltages in case of open screens are also included. For the studied cases the induced voltage is well below 1 kV for lengths up to 10 km.

Table 2: Results from the computations for the configurations in Fig. 5 at 400 A for the 12 kV cable.

Configuration	Trefoil	Flat
Power loss (grounded screen)	49 W/m	60 W/m
Power loss (open screens)	44 W/m	42 W/m
Induced currents in copper wire screen (ref. current load)	9%	16 - 22%
Induced currents in laminate (% of current load)	4%	7 – 10%
Induced voltage (open screens)	23V/km	40 - 52V/km

Table 3: Results from the computations for the configurations in Fig. 5 at 600 A for the 66 kV cable.

Configuration	Trefoil	Flat
Power loss (grounded screen)	60 W/m	85 W/m
Power loss (open screens)	49 W/m	41 W/m
Induced currents in copper wire screen (ref. current load)	13%	19 - 27%
Induced currents in laminate (% of current load)	6%	10 – 14%
Induced voltage (open screens)	31V/km	55 – 72V/km

CONCLUSION

Cables using aluminium laminate for moisture protection have been subjected to faults due to problems in the connection between the laminate and copper wire screen. Current is induced in both the laminate and copper wire screen. Proper connections between these elements are needed to transfer the current across joints and at termination ends to ground. The induced current is dependent of the configuration, cable dimension, current load, laminate and copper wire screen cross sections etc. In general compact configurations (trefoil) the induced currents are smaller than for wider configurations (flat). Computations have shown that the current in the laminate can exceed 10% of the load current.

Screen currents can be avoided (reducing the power losses) by cross bonding of cable screen or grounding the screens at one end only ("open screens"). However, this requires an evaluation of induced voltage during normal operation, at fault conditions and due to transients related to switching and lightening.

REFERENCES

[1] Eberg, Hvidsten, Bergset, " Assessment of Overheating in XLPE MV Cable Joints by Partial Discharge Measurements". Paper C1.1, Jicable 2015, Versailles.

[2] Sivertsvoll, Rønningen, Faremo, Lervik, Hønsi, Wilnes, Jacobsen, Halvorson, "Watertight Cable Designs in Hydropower Generation Plants". Paper E6.6, Jicable 2015, Versailles.

[3] COMSOL MULTIPHYSICSTM (2014), www.comsol.com. (Computer software for 2D/3D FEM analyses).

[4] Flux 2D/3D (2014), www.cedrat.com. (Computer software for 2D/3D FEM analyses).