TECHNICAL IMPLEMENTATION OF CROSS BONDING ON UNDERGROUND HIGH VOLTAGE LINES PROJECTS

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ABSTRACT

In three-phase underground systems of monopole cables the metallic sheaths are connected to earth at certain points of the circuit. The alternated current that flows on the conductor core causes energy losses on the sheaths due to the inductive and Foucault currents, which results in additional losses decreasing the transmission capacity of the power lines. A solution to reduce those losses is to connect the shield to earth. This paper presents the main differences between the several methods of connecting the sheaths to the earth, to reduce the losses and to improve the distribution capacity. It will be also presented a case study that supports a technical and economic validation of cross bonding implementation on the project phase.

INTRODUCTION

In three-phase underground systems of monopole cables the losses of a cable on permanent regime can be expressed, according Neher-McGrath, through the following circuit:

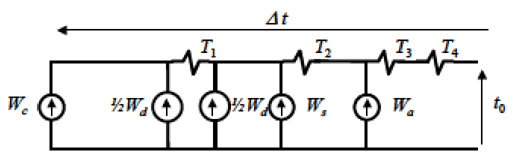

Figure 1. Equivalent electrical scheme [1]

Considering the Figure 1, it can be obtain the temperature variation, Δt, through the following equation:

$$\Delta t = \left(W_c + \frac{1}{2}W_d\right)T_1 + (W_c + W_d + W_s)T_2 + (W_c + W_d + W_s + W_a)(T_3 + T_4)$$

Equation 1

Where:
W_c: Conductor Joule losses;
W_d: Dielectric losses on the conductor isolation;
W_s: Sheath losses;
W_a: Armour losses;
T_1: Thermal resistance between the conductor and the sheath;
T_2: Thermal resistance of the internal sheath;
T_3: Thermal resistance of the external sheath;
T_4: Thermal resistance of the environment.

To derive an expression from where the ampacity can be directly calculated, the heat sources W's, that represent the electrical losses, are expressed as proportion of the Wc – the conductor losses. The conductor losses are obtained through the conductor resistance and the respective current. Thus,

$$W_s = \lambda_1 W_c$$

Equation 2

$$W_a = \lambda_2 W_c$$

Equation 3

$$W_c = RI^2$$

Equation 4

Where:
λ_1: Sheath loss factor;
λ_2: Armour loss factor;
R: Resistance of the conductor at service temperature;
I: Conductor current carrying capacity at permanent regime.

Substituting the equations 2, 3 and 4 in the Equation 1 results:

$$I = \sqrt{\frac{\Delta t - W_d\left(\frac{1}{2}T_1 + T_2 + T_3 + T_4\right)}{RT_1 + R(1 + \lambda_1 + \lambda_2)(T_3 + T_4)}}$$

Equation 6

The Equation 6 allows to quantify the losses on a circuit of underground cables, namely to different types of sheaths connections to earth as it is presented on the section of the "Case Study" section. Note that for different types of sheaths connection to earth, keeping the other installation conditions of constant, just change the loss factor λ.

SHEATHS CONNECTIONS TO EARTH SCHEMES

To reduce the influence of the sheaths current on the energy losses, one of the schemes presented can be applied to connect the shields to the earth. Thus, it is possible to increase the cable current carrying capacity as well as make the three-phase system more balanced.

Both ends bonding

The magnetic field effect caused by the phase conductor current induces a longitudinal voltage along the metallic sheaths of the cables. This voltage is proportional to the length of the underground power line. Therefore, to reduce the risk of excessive voltages the sheaths are grounded at their both ends.

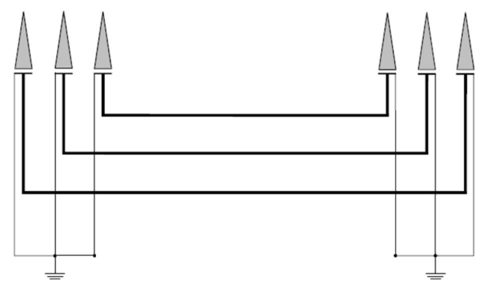

Figure 2 – Both ends bonding

As it can be verified in Figure 2, this scheme establishes a closed circuit for the induced currents. The induced currents circulation results in heat and consequent reduction of cable current carrying capacity. The constant current flow through the sheaths during normal operation of the power line leads to increased losses and to the need of oversize the section of the cable conductors to guarantee a certain carrying capacity. Given the above, to avoid this disadvantage the sheath circuit should be interrupted or the sheaths should be connected to the earth according particular schemes which do not allow the closed circuit between them.

One end bonding

To eliminate the effect of the induced current, one of the sheath ends can be disconnected. However, in this situation it can be observed on the other end of the circuit an increasing of the voltage that is proportional to the length of the line, as well as a potential difference between the sheaths. As long the circuit is, the voltage on the sheaths can take prohibitive values.

Single point

For circuits up to 1 km [2], the effect of the potential increases can be minimised introducing a sheath voltage limiter (SVL) in star configuration with the centre connected to earth. The SVL lock the circulation of current in normal operation and in case of short circuits.

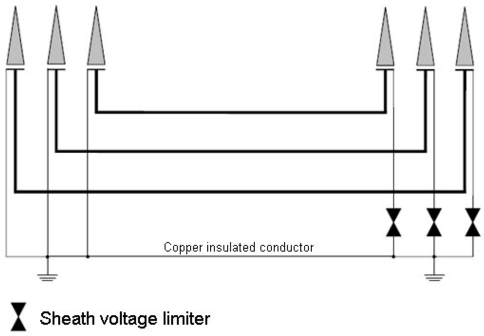

Figure 3 – Single point bonding [2]

The point at which the shields are bonding between them and connected to the earth is one of the ends of the power line. Although, if in this situation are generated high voltages on the sheaths the bonding point can be moved to an intermediate point.

In this method, it is provided a return circuit for the induced currents through an earth copper continuity conductor [3] that allows balancing the electrical potential at both ends of the circuit, avoiding constant flowing of the currents by the sheaths during normal operation of the power line. The continuity conductor should be insulated to prevent corrosion problems and it should be installed as close as possible to the three-phase circuit to minimize the voltage increase results from a defect in one phase. The section and electrical conductivity of that conductor should be suitable for the short-circuit current of the system.

A disadvantage on this method is the fact that it only can be implemented on limited lengths of cable because the induced voltages are proportional to the circuit length.

Cross bonding

For underground circuits longer than 1 km, the losses on the metallic sheaths can be minimized making in each joint a cross bonding of the cable shields. This method consists in dividing the cable length into three approximately equal sections with the sheaths connected and grounded at the ends of the circuit. Thus, the vectorial sum of the induced voltage is practically null. The natural points to establish the crossings are the joints, where appropriate cross bonding boxes to the sheaths. These boxes include SVL.

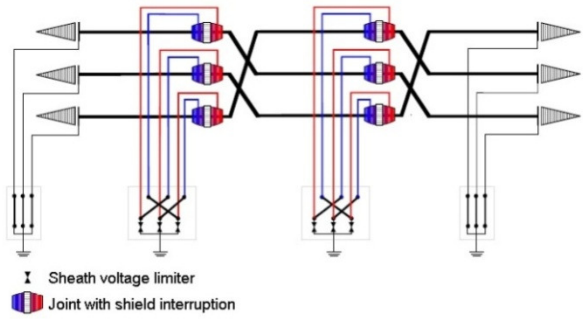

Figure 4 – Cross bonding [2]

In this solution, the length of the circuit is not a limitation. For this reason, the cross bonding sheaths has a greater applicability to the electrical distribution systems. The main disadvantage of this method is because it can become an expensive implementation.

CROSS BONDING COMPONENTS

To a cross bonding system implementation the following equipments are applied:

a) Cross bonding boxes to execute the crossing of the sheaths. These boxes include SLV and each box should have an earth electrode itself for create an earth return circuit in each divided section of the line.


Figure 5– Cross bonding box [4]

These boxes should be watertight and capable of containing the effects of the thermal or electrical failures of any element inside the box, including a possible internal short circuit.

To facilitate its maintenance, these boxes should be installed in joints boxes with easy access (for example through the placement of manholes) and they should not be at more than one meter below the ground level [3].

b) Direct bonding boxes are usually applied on the ends of the line to connect the sheath directly to earth. These boxes include earth electrode but, unlike cross bonding boxes, they do not include SLV.

c) Kits for shield interruption: it is necessary for each phase joint to introduce an additional kit to remove the shield outside the respective box and to connect a concentric cable. Is this coaxial cable that will connect the sheaths to the cross bonding boxes.

d) Cables to the sheaths connection to cross bonding boxes: should be coaxial cables insulated with XLPE (cross linked polyethylene) or flexible monopole conductors. The section of these cables is determined by the maximum value of short circuit current of the power line.

Considering the monopole conductors solution, instead of the coaxial cables one, it is not necessary to include the additional kits for shield interruption. Thus, the monopole conductors are directly connected to the cross bonding boxes.

The sheaths connections should be designed to minimise the cable length, which should not exceed the 10 meters [3].

Figure 6 – Cross bonding installation

CASE STUDY

The case study presented is an underground power line, with a nominal transport capacity of 120 MVA, through three-phase alternated current with a frequency of 50 Hz and a voltage of 63kV. This line is constituted by six LXHIOLE 1x1000/135 mm^2 cables and its length is 2.900 meters.

The analysis of the carrying-current capacity in the scenarios following presented had the cooperation of a firm representative of the cables sector that developed the sheath loss studies regarding different types of connections to earth.

In the economic assessment performed, it was not considered the costs related to men power regarding the implementation neither to costs of maintenance.

SCENARIO I - Cross bonding solution

To minimise the cables sheaths losses by cross bonding implementation, the total circuit was divided in six sections of identical lengths, as it is illustrated in Figure 7.

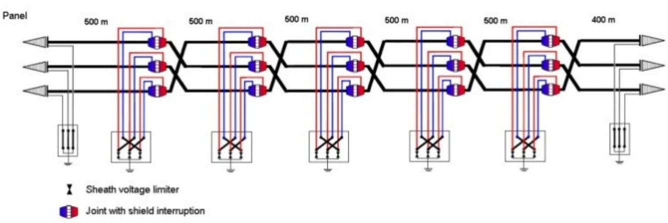

Figure 7 – Scenario I connections scheme (cross bonding)

A market survey was conducted for the equipment costs to implement the scenario I resulting in a total investment cost of 48 k€. Analysing the graphics in Figure 8 and 9 it can be verified that for nominal load capacity, the cross bonding implementation represents a gain of 10.600W (17.000 W – 6.400 W) related with the sheaths losses by the Joule effect, per cable, comparing to the both ends bonding solution.

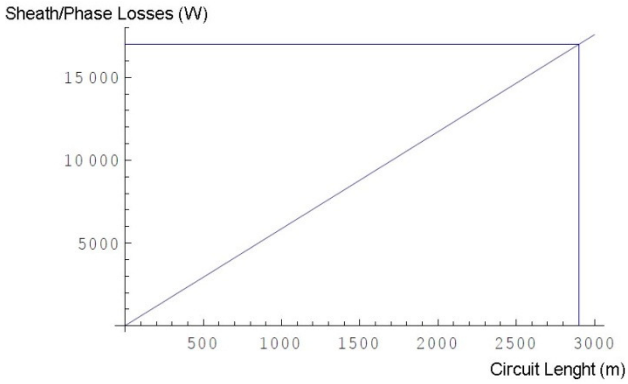

Figure 8 – Shield losses with both ends bonding [2]

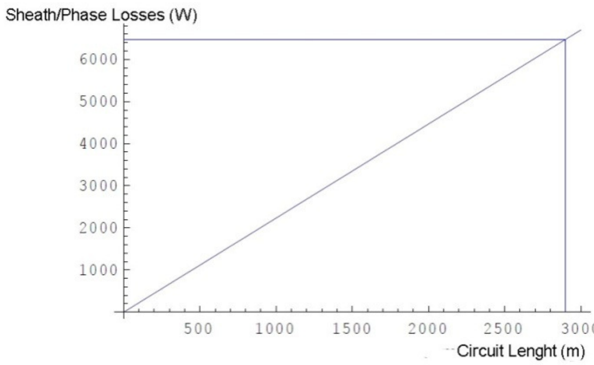

Figure 9 – Shield losses with cross bonding [2]

SCENARIO II - Single point solution

To minimise the cables sheaths losses by single point implementation, the total circuit was divided in four sections of identical lengths, as it is illustrated in Figure 10.

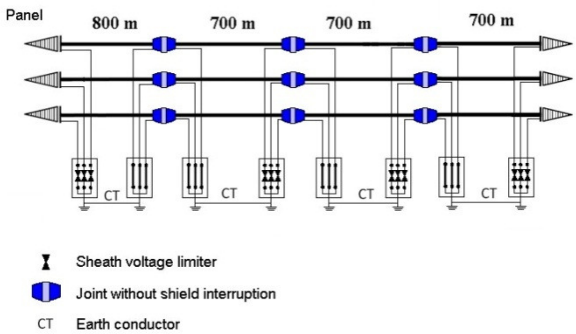

Figure 10 – Scenario II connections scheme (*single point*)

For the equipment applied in scenario II the cost investment is 208 k€. Analysing the Figure 11 graphic, for nominal load capacity, the single point solution results in a gain of 12.200 W (17.000 W - 4.800 W) per cable, regarding the sheath losses, when compared to the both ends bonding solution.

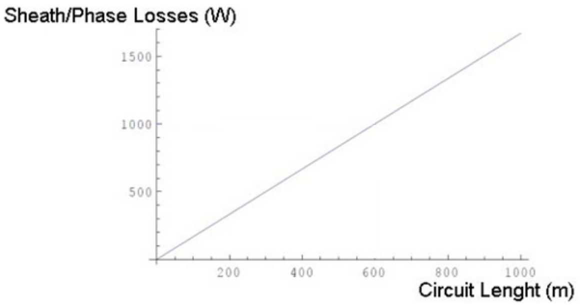

Figure 11 – Shield losses with single point bonding [2]

Analysing of the scenarios described previously, and considering an operation of 60% of the nominal load capacity, for the scenario I (cross bonding solution) it results in a gain of approximately 56 MWh per cable per year. Assuming that the unit losses value is 0,0595 €/kWh, it would be obtained a total losses cost of 3.300€ per year and per cable, so for the six cables it would be 20 k€ per year.

For the scenario II (single point solution), and considering an operation of 60% of the nominal load capacity, it was obtained a gain of approximately 64 MWh per cable per year. Assuming that the unit losses value is 0,0595 €/kWh, it would result in a total cost losses of around 3.800 € per year and per cable, so for the six cables it would be 23 k€ per year.

As a conclusion, it can be calculated that for the scenarios I and II the amortisation period of the respective investments are 2,5 and 9,0 years, respectively.

CONCLUSIONS

In a three-phase alternated current, the system formed by the shields and their connections is a secondary circuit strongly linked to the primary circuit, formed by the main conductors submitted at the grid voltage. Thus, during the normal operation of phase cables it may appear considerable intensity currents flowing at the shields that generate additional losses.

The type of the sheaths connection to earth influences the ampacity in the monopole underground cables, reflected by the loss factor λ (see Equation 6). Actually, this can be considered the second most important parameter for calculating the current-carry capacity in a cable, after the external thermal resistance of that cable. For this reason, it is an important aspect to be considered at the design and construction of underground power lines.

Considering the additional losses and heating due to the current shield, it should be and adopted, in many cases, mitigation methods. It is characterised in this document schemes for grounding the shields more often used:

- Both ends bonding;
- One end bonding;
- Single point;
- Cross bonding.

The system grounding at both ends provides a closed circuit for the induced currents generating additional heat production, with the consequent reduction of the transmission capacity of the line.

To avoid these additional losses, the shields are connected to earth following schemes which exclude the formation of close circuits between them, or that can cancel the electromotive forces induced in the possible closed circuits. Achieved that objective, it appears in addition to the benefits referred, two others:

- The separation distance between phases can be increased to achieve better heat dissipation to the environment;
- As the necessary conductor section can be smaller the capacitive current absorbed by the line is also lower.

For the case study presented are remarkable the gains inherent in these types of solutions - cross bonding and single point. Moreover, it is concluded that the amortisation period of investment required for their implementations is reduced when compared with the lifetime of an installation of underground high voltage power lines- 30 years.

Considering the data presented in the case study, the gains obtained during the lifetime of an underground line are approximately 550 k€ and 480 k€ to the solutions of the cross and single point bonding, respectively. Additionally, it is the solution of cross bonding that is the most advantaged because it has an initial investment of about three times lower than the single point solution.

On the other hand, the single point solution increases men power for their implementation and maintenance costs, inherent in the earth continuity conductor. Moreover, the reliability of this kind of systems can also become smaller because of the existence of the additional conductor between the direct bonding boxes and the boxes with SLV that in case of defect is not easily detectable.

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