CASE STUDY OF THE IMPLEMENTATION OF CROSS-BONDING TO UNDERGROUND LONG MEDIUM VOLTAGE CABLES IN WIND PARKS

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ABSTRACT

Cross-bonding, i.e. the special bonding in which the metallic sheaths of different phase power cables in successive minor sections are cross-connected in such a way so as to attain partial or full cancellation of induced currents on the metallic sheaths, is implemented in an effort to reduce the energy losses and improve the sheath voltage distribution. This paper deals with the implementation of cross-bonding to underground long medium voltage single conductor cables, which are widely used in the interconnection of wind parks to the power grid over the last years.

INTRODUCTION

The optimal operation of high voltage and medium voltage cables, concerning their efficiency and the reduction of power losses, is an issue of high importance, considering the initial investment cost and the repercussions of a potential fault that results in power supply interruption and severe replacement and/or repair costs. In an effort to enhance the operation of the cables, cross-bonding, i.e. the cross-connection of the metallic sheaths in successive minor sections, can contribute to the reduction of the power losses; indeed, the cross-bonding of the sheaths cancels the total induced voltage generated in the sheath of each phase, minimizing the energy losses, both for the case of single-phase and three-phase faults [1]. For the analysis in this work the metallic cable screens are referred to with the more familiar term "cable sheaths" [2].

To this context, the present work deals with the implementation of cross-bonding to underground long medium voltage single conductor cables, which are widely used in the interconnection of wind parks to the power grid over the last years. The paper summarizes the basic principles of cross-bonding and computes the developed voltages and currents for various cases, examining the impact of different cross-bonding techniques on the developed sheath voltages along the cables.

GENERAL FORMAT

Although cross-bonding is mainly applied to High Voltage (HV) cables, during the last decade has also been used in the Medium Voltage (MV) cables of wind parks, due to the long distances between the wind turbines and the substations. The main function of the metal sheath is to neutralize the electric field of the cable by providing a return path of the charging and fault currents to ground during a short circuit. Analysis of the induced currents caused by the adjacent cables' magnetic fields for the alternative sheath bonding arrangements is of significant importance.

In case of the solid bonding the sheaths are connected and earthed at both ends of the run so circulating currents are produced from the magnetic field of the conductors balancing the developed induced voltages. Losses due to circulating currents are usually much greater than those of eddy currents.

At single-point bonding arrangement only one end is grounded, therefore, circulating currents are eliminated as a closed loop with the earth is not created. In systems with single conductor cables, induced voltages and eddy currents are developed due to the magnetic flux that penetrates the sheath. The induced voltage between the sheath and the earthed end is proportional to the length of the system resulting in cable length limitation for this bonding method. Thus, in large systems, induced voltage values can be reduced using the multi single-point bonding where the cable sheaths are grounded at various points along the cable path.

In the cross-bonding arrangement, electrically continuous sheath runs from earthed termination to earthed termination are provided, but the sheaths are sectionalized and cross-connected in order to reduce the sheath circulating currents and losses (Figure 1).

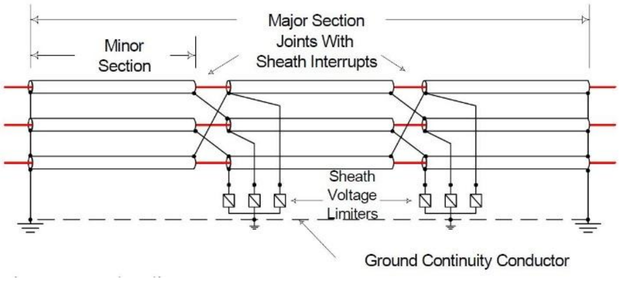

Figure 1: Implementation of cross-bonding [3].

Usually, the cable is sectionalized in three sections of approximately the same length; the sheaths are grounded at both ends and are cross-connected between the sections in appropriate link boxes. The trefoil layout and cross-bonding of the cable sheaths between the sections eliminate the induced voltage. The aforementioned three sections (minor sections) constitute a major section and according to the system cable length a number of major sections in a row can be used. It is not generally possible to divide the route length into exactly matched minor section lengths, nor is it always possible to maintain a constant spacing of the cables throughout the route. Due to the different site situations, other scenarios can be applied to the cross-bonding achieving the best results, and reducing the induced sheath voltage as well.

Two typical cross-bonding layout types are shown in Figures 2 and 3. In the sectionalized cross-bonding method (Figure 2) the sheaths are grounded and not cross-bonded between the major sections whereas in the continuous cross-bonding method (Figure 3) the sheaths are cross-bonded and not directly grounded between the major sections. Usually, sheath voltage limiters (SVL) should be used at these link boxes between sheaths and earth.

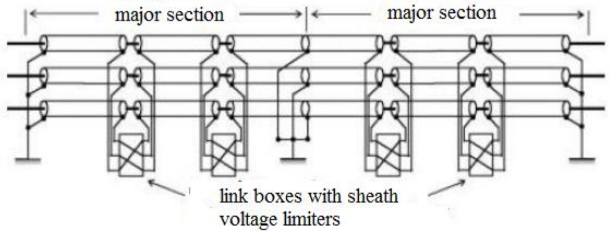

Figure 2 – Sectionalized cross-bonding method [4].

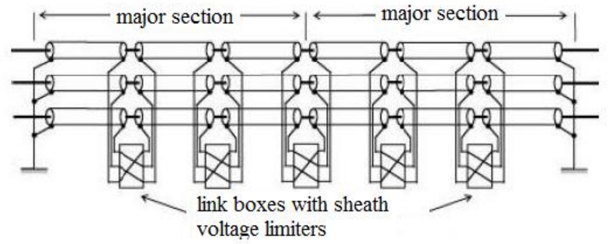

Figure 3 – Continuous cross-bonding method [4].

Cross-bonding advantages include:

- Minimizations of circulating currents, induced voltages reduce and consequently, lower losses. Thus, it outperforms both the solid bonding and the single-point bonding.
- Due to the low induced voltage values, greater length MV transmission lines construction is enabled using more major sections.
- Earth resistance and zero-sequence impedance are improved due to grounding of both ends [5].
- It is not necessary to install a ground continuity conductor.
- Due to specialized joints, extra testing is required during the installation, resulting in a lower number of failures and low maintenance.

However, cross-bonding has also disadvantages, i.e.:

- Installation cost increase.
- Greater technical complexity.
- The outer sheath interruption of the cable at several points introduces an additional problem in the partial discharge (PD) location based on the time-domain reflectometry (TDR) system [6].

SYSTEM DESCRIPTION

The objective of the present analysis is to compare various cable configurations used for the interconnection of an onshore wind park in Greece with the local 20 kV (or 33 kV)/150 kV substation of the transmission grid. The wind park consists of 9 wind turbines, 4.2 MW each, and 3 wind turbines, 3.6 MW each. The cable configurations examined differ in terms of cross-section of the cables, 800 mm^2 and 630 mm^2, voltage level, 20 kV and 33 kV, and total cable length from 5 km to 23 km.

A group of 6 medium voltage (MV) single-core cables type AL/XLPE/AL-PE/MDPE is installed in an underground arrangement of triple 3-phase circuit S1 and S2 with the cables in trefoil formation in each circuit. The cable ditch has a total depth of 1.2 m. Each cable consists of an aluminium core with XLPE insulation and AL/PE metallic screen with MDPE outer insulation. Grounding resistances at the TG and WP sides are assumed 1 and 10 Ω, respectively, according to the actual grounding resistances measured in the real installation.

CABLE CONFIGURATION MODELLING

In this paper a complete study is carried out using ATP-EMTP software. The starting point of the analysis, the underground cable, is the crucial element of the configuration. It is simulated by built-in LCC objects (Pi-equivalents) based on ATP-EMTP's CABLE CONSTANTS and CABLE PARAMETERS supporting routines. The selection of LCC objects is based on the instructions (version 5.6) for ATP Draw and according to corresponding studies [7, 8]. In order to achieve the same accuracy in each Pi-equivalent 300 m of cable length is represented.

Moreover, the variable parameters of cable configuration are cross-section of the cables, sheath bonding, voltage level and total cable length. Each simulation concerns a particular cable cross-section and a specific way of sheath bonding and earthing. For the steady-state simulation, the worst-case scenario corresponds to the maximum power flow from the wind park to the electric grid. Moreover, for three-phase systems, three consecutive equal minor sections are required to form a major section to minimize sheath currents in all three phases [1, 8, 9].

STEADY-STATE ANALYSIS - CASE STUDY: AN ONSHORE WIND PARK

The first analysis is a case study to show the distribution of sheath voltage and current. The cable configuration comprises a group of six MV single-core AL/XLPE/AL-PE/MDPE 19-33 (36 kV) cables from Hellenic Cables S.A. with a cross-section of 800mm^2 in trefoil formation. The cable installation has a total length of 21 km. Cable length l is measured starting from a zero value (0 %) at the wind park and retains a 21 km value (100 %) at the corresponding point at the cable connection point to the substation.

In the case of single-point bonding and grounding only at one end of the substation, we notice an increase in voltage at the end. The maximum voltage at the bare end reaches a maximum of 824 V (Fig. 4). On the other side when the grounding is on the control center side and with the change of the grounding resistance and side, voltage will be almost the same at this case (819 V). Furthermore, when cable sheaths are solidly bonded and both cable ends are grounded, the induced sheath voltage improves reaching up to a maximum of 360 V.

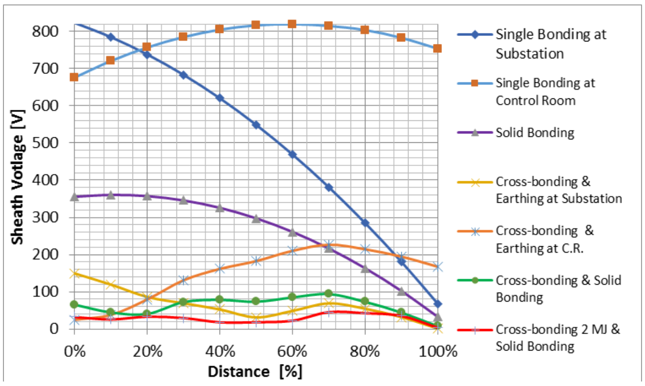

Figure 4 - Sheath voltage distribution for various sheath-bonding for cables of 800 mm^2.

In cases of cross-bonding and single-point (end) bonding the value of voltage reaches a maximum of 150 - 227 V. The application of cross-bonding with solid bonding significantly reduces the induced sheath voltage to a maximum of 93 V for 1 major section (3 minor) and below 50 V for 2 major sections (5 minor). Compared to single-point bonding a reduction of 89-94 % is achieved.

Figure 5 illustrates the sheath current distribution for the above cable system. In cases of cable sheath grounding either with single-point or solid bonding, the induced current values become high, causing increased cable losses. In this case, the implementation of cross-bonding makes a great difference reducing the induced currents to a maximum of 22 A. Combined cross-bonding and solid-bonding arrangements result in a 15 A sheath current maximum value. Especially, cross-bonding with two major sections (5 minor) succeeds to reduce sheath current even more achieving a 7.5 A maximum. Hence, significant mitigation of cable power losses is achieved in this way.

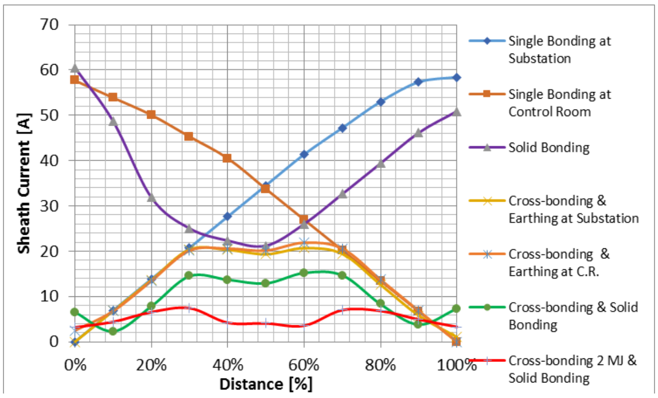

Figure 5 - Sheath current distribution for various sheath-bonding for cables of 800 mm^2.

PARAMETRIC ANALYSIS

The objective of this parametric analysis is to compare various cable configurations with the implementation of Cross-bonding with one major section used for the interconnection of an onshore wind park in Greece with the local 20 kV (or 33 kV)/150 kV substation of the transmission grid. This analysis contributes to the guidelines for the selection of the final cable configuration. The cable configurations examined differ in terms of cross-section of the cables, 800 mm^2 and 630 mm^2, voltage level, 20 kV and 33 kV, and total cable length from 5 km to 23 km.

For this parametric analysis 28 different simulations have been conducted and the voltage distribution along the cable sheaths has been calculated using the ATP-EMTP software. To compare the influence of the different parameters to the cable configuration, Figure 6 shows the maximum of the sheath voltage at each simulation for the particular cable configuration. Here, only the maximum is shown, since the aim is to reduce the maximum sheath voltages and currents on the cable sheaths. It is shown that as the total cable length increases the induced sheath voltage is getting even more significant and may exceed the limit set by each country or electric utilities.

According to the new revised IEEE Standard 575-2014 (Revision of IEEE Std. 575-1988) [1] there isn't a generally accepted limit for maximum steady-state sheath standing voltage levels. In Great Britain the Energy Networks Association has published engineering recommendation C55 (Issue 5 2014) [9]. According to this sheath bonding and earthing arrangements shall be such that the standing sheath voltage at maximum declared full load current shall nowhere exceed the historically accepted values of 65 V for system voltages from 33 kV up to and including 132 kV.

The increase of sheath voltages can be confronted with either the application of more major sections of cross-bonding or another scheme of cross-bonding or even with the change to another voltage level. The application of new substations 33 kV/150 kV in Greece inducted new needs for the examination, calculation and comparison with the existent cable interconnections to substations 20 kV/150 kV. The difference in terms of sheath voltage between the two voltage levels starts from 20 V increases with the total cable length until it reaches up to 75 V for the same cross-section.

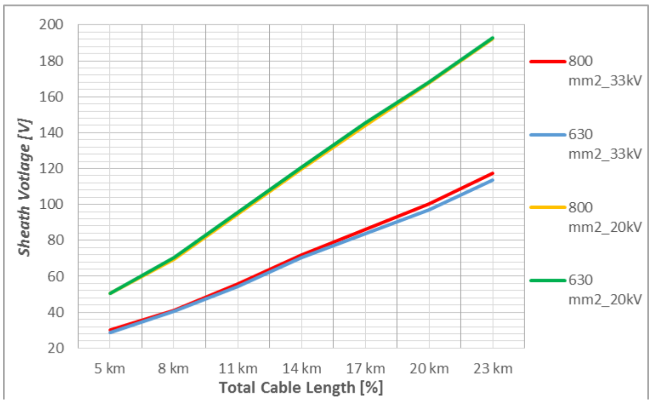

Figure 6 - Sheath voltage distribution for various cable lengths, cross-sections and voltage levels.

Here, is another interesting fact. For the same full load of the specific wind park, losses and sheath voltage are quite close for different cross-sections and a little increased for greater cross-section. This can be better presented in Figure 7 where the gap between different cross-sections for sheath currents is more evident. Cable failures experience has shown that sheath currents over 10-15 A should be dealt with because except from redundant losses they can gradually cause cable failures.

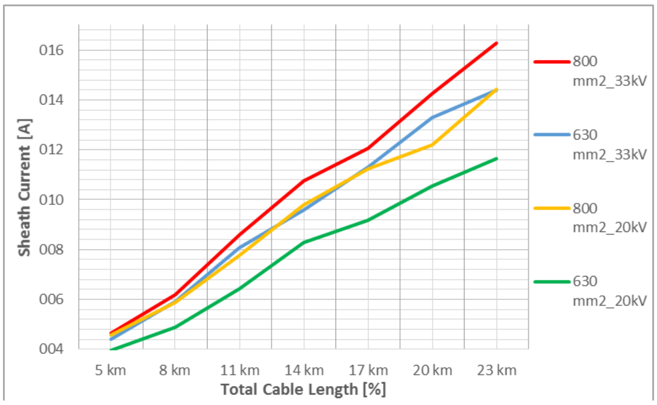

Figure 7 - Sheath current distribution for various cable lengths, cross-sections and voltage levels.

CONCLUSION

This paper deals with the implementation of Cross-bonding to underground long medium voltage single conductor cables which are widely used in the interconnection of wind parks to the power grid. Through a case study of a real wind park, it is evident that the induced voltages and currents at the cable sheaths exceed limits and may cause cable failures. The calculation of the cable sheath voltages and currents has been conducted using ATP-EMTP software. Therefore, the proper implementation of cross-bonding can reduce sheath voltage and current successfully. Furthermore, a comparative analysis of the implementation of cross-bonding with one major section is presented. The parameters are cross-section of the cables, voltage level and total cable length. The results show that the cable sheath voltages and currents follow the same extent of increase as total cable length and the cross-section of the cable. Additionally, cable sheath voltages are greater for lower voltage level and for the maximum declared full load current that corresponds at each voltage level.

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