A Model for Assessing the Magnitude and Distribution of Sheath Currents in Medium and High Voltage Cable Lines

Roberto Candela
Prysmian Electronics srl
Via Costantino Nigra 5, 90141
Palermo, Italy
roberto.candela@prysmiangroup.com

Antonio Gattuso
Università di Palermo
Department of Engineering
Viale delle Scienze,
Edificio 9, 90128
Palermo, Italy
antonio.gattuso@community.unipa.it

Massimo Mitolo
Fellow, IEEE
Irvine Valley College Electrical Department
5500 Irvine Center Drive, Irvine,
CA 92618, USA
mitolo@ieee.org

Eleonora Riva Sanseverino
Università di Palermo
Department of Engineering
Viale delle Scienze, Edificio 9, 90128
Palermo, Italy
eleonora.raivasanseverino@unipa.it

Gaetano Zizzo
Senior Member, IEEE
Università di Palermo
Department of Engineering
Viale delle Scienze, Edificio 9, 90128
Palermo, Italy
gaetano.zizzo@ieee.org

Abstract -- **In this paper, the authors discuss a simulation model to study the effect of cross-bonding of metallic sheaths, and/or non-magnetic armors, of single-core medium- and high-voltage cables in the same circuit. In single-core cables, the resistive losses due to the induced circulating currents in cable sheaths or armors causes an increase of the cable temperature, which therefore reduces its ampacity. This is a serious issue affecting distribution and transmission lines. In addition, the risk of electric shock due to induced voltages may be present if a person is in contact with the armor/sheath at its unbounded end. For these reasons, special bonding techniques of metal sheaths are employed to reduce these currents.**

The simulation model to assess magnitude and distribution of induced armor/sheath currents of medium- and high-voltage cables that is herein proposed may be used to optimize the cross-bonding configuration of single-core cables employed in high-current industrial applications or in transmission/distribution power grids. The model has been experimentally validated by means of actual data from a high-voltage underground line and field measurements performed by Prysmian Electronics.

Index Terms—**ampacity, cables, cross-bonding, sheath currents.**

I. INTRODUCTION

The use of single-core armored/sheathed underground cables, largely employed in Europe, has driven the research for models that could accurately represent their performance in any load conditions and configurations.

The armor or sheath of a cable is an exposed-conductive-part and must be connected to ground for either TN or TT systems [1]-[2]. The connection with ground of the sheath must be made at a minimum of one point, generally at the supply end (i.e., single-point bonding), with the other end is isolated from ground.

The a.c. load current flowing through the cable induces a voltage in the armor, the metallic screen or sheath of a single-core cable. The magnitude of the induced voltage will depend on the load current, the length of the cable, the armor/sheath diameter and the cable spacing. If the armor/sheath is bonded at both ends forming a loop (i.e., solid bonding), the circulating induced current will affect the cable ampacity and there is a risk of overheating the terminations.

If the armor/sheath is single-point bonded, the risk of electric shock is present if a person is exposed to the armor/sheath at the unbounded end. In wet conditions, or in special locations, touch voltages from sheaths and/or armor to ground should not exceed 25 V (rather than 50 V) [3].

Under fault conditions, the induced voltage will be higher at the unbonded end. However, the likelihood that a person would be in contact with the unbonded end, which should be properly insulated, is deemed remote by applicable standards.

Reference [3] indicates a preference for solid bonding and requires the professional engineer to consider in the electrical design the presence of circulating currents or of the induced voltages.

Over the years, different models have been developed for the study of critical conditions of cable lines. Researchers have implemented models for different purposes, such as the analysis of the frequency and time domain response of the cable at the resonant frequencies in different cross-bonding configurations [4], the partial discharge location detection [5]-[7], the calculation of the value of the single-line-to-ground fault current in the line [1] or also to develop a fault localization method [8]-[12].

On the on the other hand, the case of Medium Voltage (MV) or High Voltage (HV) cable lines under normal operating conditions has not been fully analyzed. Normal operating conditions are of interest because of major issues, such as cable ampacity deratings and fires generated by the currents induced in the armors/sheaths. For these reasons, the authors have created and verified a model that could help simulate single-core cables employed in high current industrial applications, both in medium- and high-voltage, in normal operating conditions as well as in fault conditions.

In this paper, which is an extended version of the conference paper [13], the model has been applied to a 30 kV- distribution line in the various cross-bonding configurations as per the standard IEEE 575-2014 [10]. Cross bonding is defined in [10] as a special bonding in which the metallic shields/sheaths of different phase cables in successive minor sections are cross connected in such a way so as to achieve partial or full cancellation of induced sheath currents.

The study has provided the best cross-bonding configuration that ensures the highest shield current reduction. The shield losses were examined, as already done in [9]-[12], [14]-[15] and it was verified that a particular type of configuration could lead to a significant reduction in those losses.

Finally, the last section of the paper reports the results of the model validation.

II. MATHEMATICAL MODEL

For the implementation of the mathematical model, Carson's theory was used to determine the self- and mutual-impedances of any number of underground conductors taking into account the effect of the earth [17]. Carson's theory is the basis of the formulation usually applied for the evaluation of self- and mutual-impedances in both a.c. overhead and cable lines for steady-state studies, and is adopted by both IEEE [18] and IEC standards [19]. The formulae are usually referred to as "approximate" [20], whereas more complex expressions may be found in the literature for the same calculations [21]-[22]. For example, in [22], the authors develop formulae based on those proposed by Carson's but more suitable for short parallel or angled conductors. However, the differences between the values calculated with these formulae and those calculated by using Carson's approach differ by few percentage points for lines whose length is over 100 m, like those for which there is a need for cross-bonding.

Self- and mutual-impedances of conductors and sheaths take into account the effects of magnetic fields, generated by a current-carrying conductor in the presence of other conductors and the earth.

To define the self-impedance, refer to an ideal thin cylindrical conductor, with an ideal sinusoidal generator connected to one end that generates a current of effective (r.m.s.) value *I*. The remote end of the conductor is solidly connected to ground. The system is shown in Fig. 1.

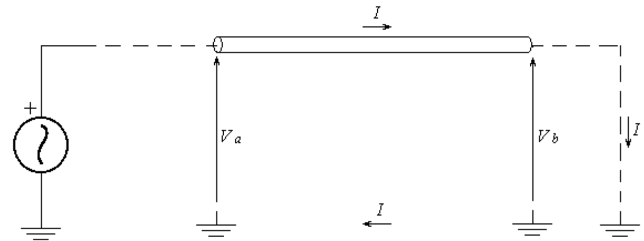

Fig. 1. Reference system for calculating the self-impedance per unit length of a thin conductur according to Carson's theory.

The current *I* circulates in the loop consisting of the conductor and the earth, which causes a voltage drop defined by:

$$\overline{\Delta V} = (r + \pi^2 f 10^{-4} + j\omega \frac{\mu_0}{2\cdot\pi} \cdot \ln \frac{2\cdot H}{0.78\cdot r_c}) \cdot l \cdot \bar{I} \quad (1)$$

where the vector sign identifies phasors.

Based on Eq. 1, the conductor's self-impedance per unit of length is defined as:

$$z = r + \pi^2 f 10^{-4} + j\omega \frac{\mu_0}{2\cdot\pi} \cdot \ln \frac{2\cdot H}{0.78\cdot r_c} \quad (2)$$

with:

- r electrical resistance of the conductor per unit of length [Ω/km];
- f frequency of the current [Hz];
- l length of the conductor [km];
- ω pulsation of the system [rad/s];
- μ_0 magnetic permeability of air [H/km];
- $2H$ distance between the equivalent conductor representing earth and the conductor [m];
- r_c radius of the conductor [m];
- ρ_E soil resistivity [Ωm]

and:

$$H = 330 \cdot \sqrt{\frac{\rho_E}{f}} \quad (3)$$

The same formula is used to evaluate the impedance of the sheaths, considering its electrical resistance and the radius of the equivalent conductor.

For the determination of the mutual impedance per unit length between two conductors (either phase-to-phase, sheath-to-sheath or phase-to-sheath) in the presence of the soil (Fig. 2), the following expression is used:

$$z_m = \pi^2 \cdot f \cdot 10^{-4} + j \cdot \omega \cdot \frac{\mu_0}{2 \cdot \pi} \cdot \ln \frac{2 \cdot H}{D} \qquad (4)$$

being D the distance between the two conductors [m].

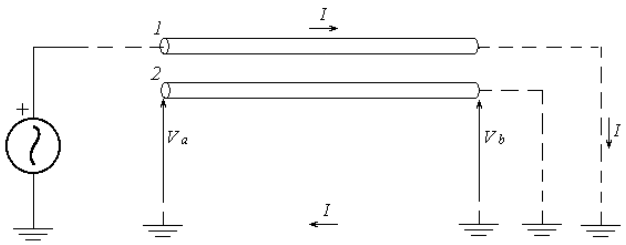

Fig. 2. Reference system for calculating the mutual impedance per unit length between two thin conducturs according to Carson's theory.

Based on the above equations, the model of a MV "minor cable section", defined as "the length of cable between shield/sheath sectionalizing insulators, and between sheath insulators and sheath end-bells at the cable terminations" [10], is found and represented in Fig. 3; the model has been implemented in MATLAB/Simulink environment.

The model includes the cable's capacitances between the phase conductors and the sheaths and allows the simulation of various configurations of a generic line composed by more minor sections. These capacitances are often omitted in the line representations used in single-line-to-ground fault studies, being usually their effect negligible in presence of a low-impedance fault [11]. However, this assumption is not always acceptable, particularly in the case of MV lines operated with an ungrounded source, when the current distribution is examined in normal operating conditions, like in the present study.

In Fig. 3, A, B and C are the phase conductors and SA, SB and SA are the cable sheaths. The capacitance, the self- and the mutual-impedance blocks adopted in the circuit representation of the minor sections have been highlighted.

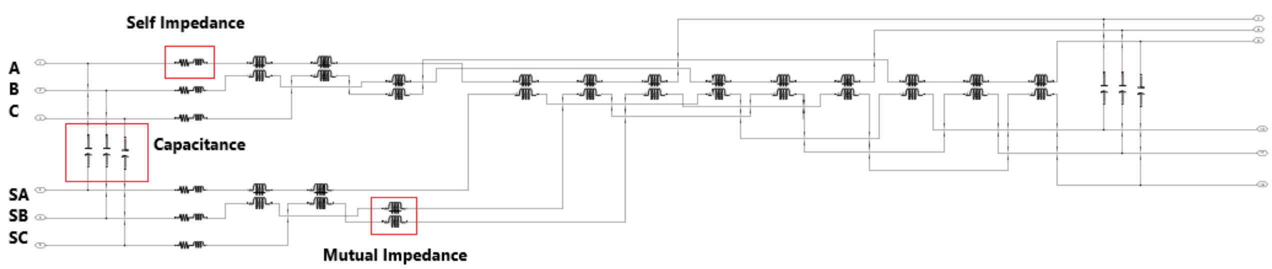

Fig. 3. Representation of a minor section in Simulink.

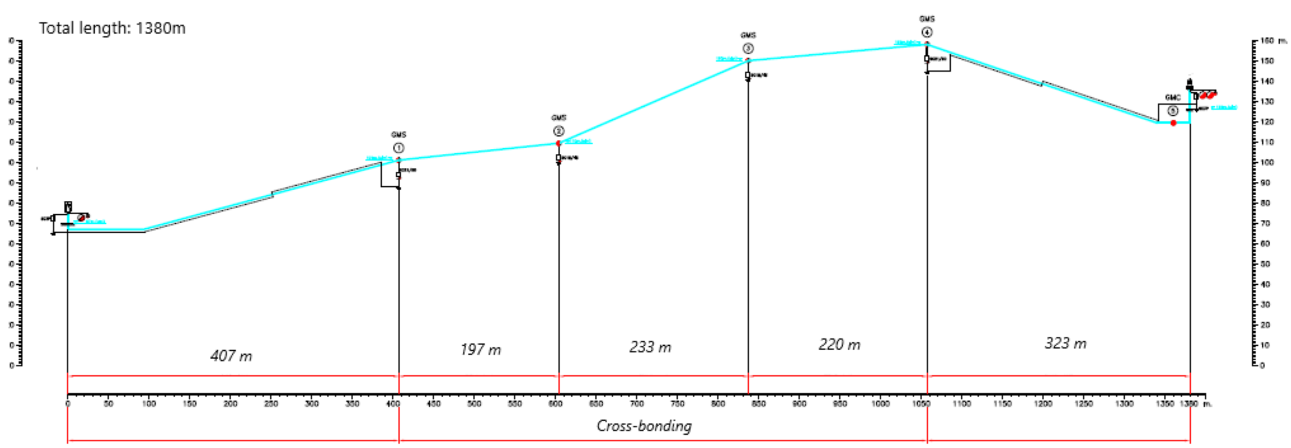

Fig. 4. Distribution line layout.

III. CASE STUDIES

The 30 kV-, 900 A-distribution line in Fig. 4 is analyzed. The line is 1380 m long, and is divided into 5 minor sections. Table I reports the length of each minor section.

Three cables were in a flat formation and laid in one plane with an equal spacing D of 40 cm (Fig. 5).

Various configurations of the above line were simulated, with and without cross bonding.

TABLE I
LENGTH OF THE MINOR SECTIONS.

Minor section	Length [m]
1	407
2	197
3	233
4	220
5	323

The cable data are shown in Table II.

TABLE II
CABLE DATA.

Cable data	
Cross-section	630 mm^2
Resistance	0.0283 Ω/km
Conductor diameter	51.3 mm

The configurations that were studied were:

- Case 1: line without cross bonding and solid bonding of the sheath;
- Case 2: line with cross bonding and solid bonding of the sheath;
- Case 3: line with cross bonding and one-point bonding of the sheath.

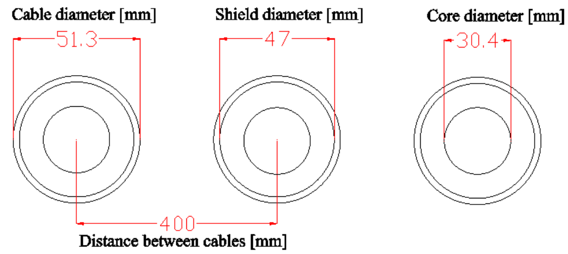

Fig. 5. Cable installation.

A. *Case 1*

This configuration is studied to show how, in the absence of cross bonding, the cables would be subjected to damaging induced currents (Fig. 6).

Between each minor section (numbered one through five), voltage and current measuring scopes are placed. A generation block and a load block to simulate the various configuration of the line are present.

Fig. 7 shows the sheath currents as a function of time, whereas Table III reports the peak values and RMS values of the currents, which are almost the same across the three phases.

TABLE III
PEAK AND RMS VALUE OF THE SHEATH CURRENTS IN THE CASE 1.

Sheath currents		
	Peak value [A]	RMS value [A]
Isa	641	453.3
Isb	599	423.6
Isc	724	512.0

These values of sheath currents are not acceptable, because they are comparable to the load operating currents. In this configuration, the cable is the equivalent of the primary of a transformer with almost unitary ratio, whereas the sheath is the secondary winding.

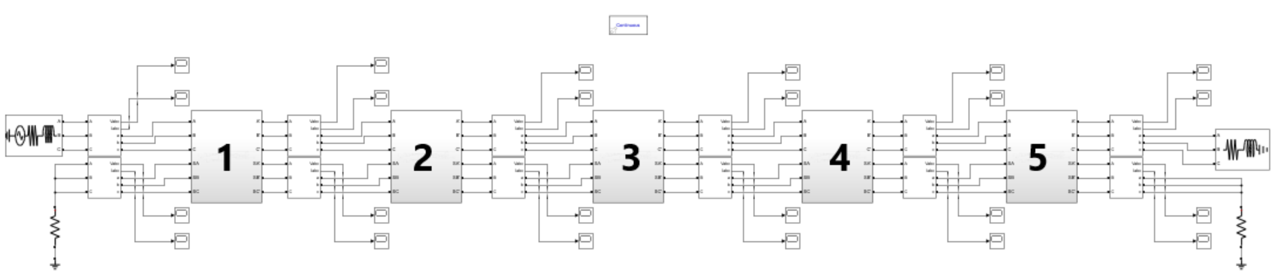

Fig. 6. Simulink model - Case 1.

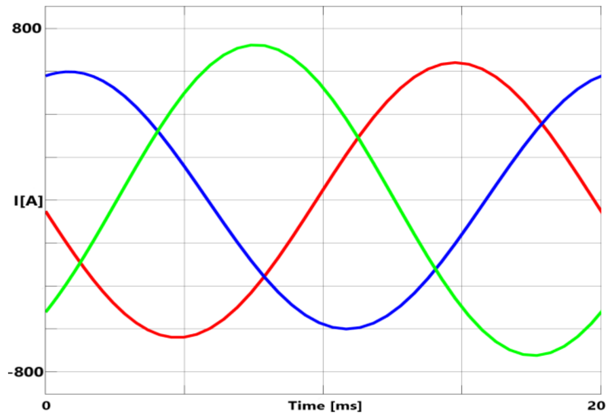

Fig. 7. Sheath currents - Case 1.

B. Case 2

In this configuration, the cross bonding is carried out between the minor sections 2, 3 and 4 (Fig. 8). The red boxes show how the cross bonding is applied in the simulation model. In this case, the solid bonding of the screens is placed at the ends of sections 2 and 4. This represents the best solution for the case, in fact, the sheath current assume the lowest value.

The trends in Fig. 9 shows how the cross bonding allows a considerable reduction of shield currents. An imbalance of the sheath currents is also present; this is due to various factors among which the most significant are the laying of the conductors and the different length of each minor section. In an ideal system, the use of cross bonding would have eliminated sheath currents, except the modest leakage current due to the capacitive coupling between conductor and sheath. This configuration reduces sheath current magnitudes (Table IV) under normal operating conditions, but does not completely remove them. The problems of cable ampacity derating and risk of fire may therefore still be present.

TABLE IV
PEAK AND RMS VALUE OF THE SHEATH CURRENTS IN THE CASE 2.

Sheath currents		
	Peak value [A]	RMS value [A]
Isa	37.3	26.4
Isb	23.6	16.7
Isc	36.6	25.9

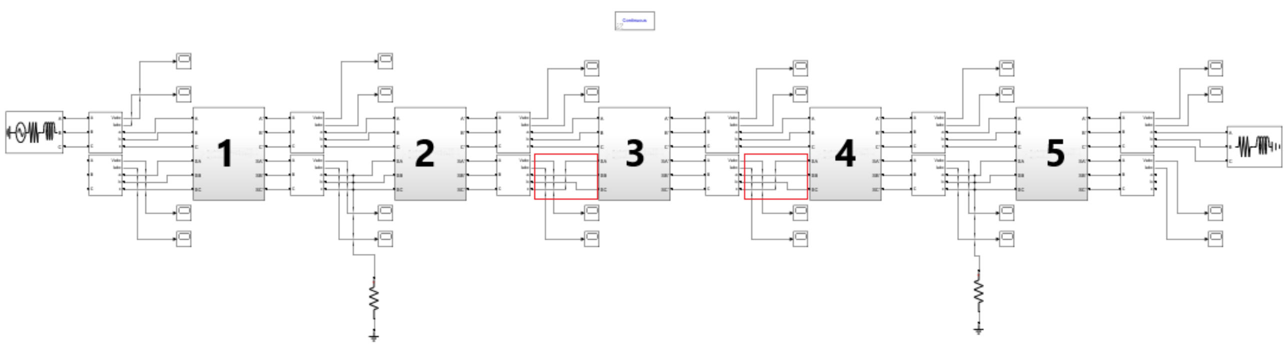

Fig. 8. Simulink model – Case 2.

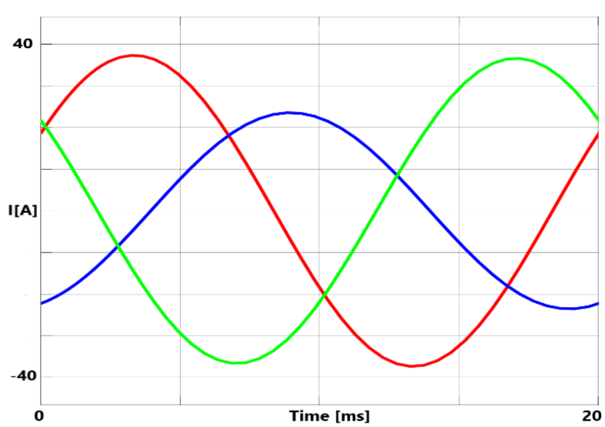

Fig. 9. Sheath currents - Case 2.

C. Case 3

This configuration is based on a sheath connection method called single-sheath bonding [16].

To limit the voltage rise of the sheath during ground faults, the single-point bonding installation does require a parallel conductor, grounded at both ends of the cable route and installed very close to the cable conductors. This parallel conductor will carry the fault-current, and will add to the cost of the implementation of the cable system.

The single-sheath bonding reduces this cost by employing one of the cable sheaths, solidly grounded at both ends, as the parallel conductor. The sheath is in proximity to the single-point bonded cable circuit and provides the required continuous metallic connection between the grounding points at the ends of the cable route.

Based on this type of bonding, cross bonding is carried out according to the scheme in Fig. 10.

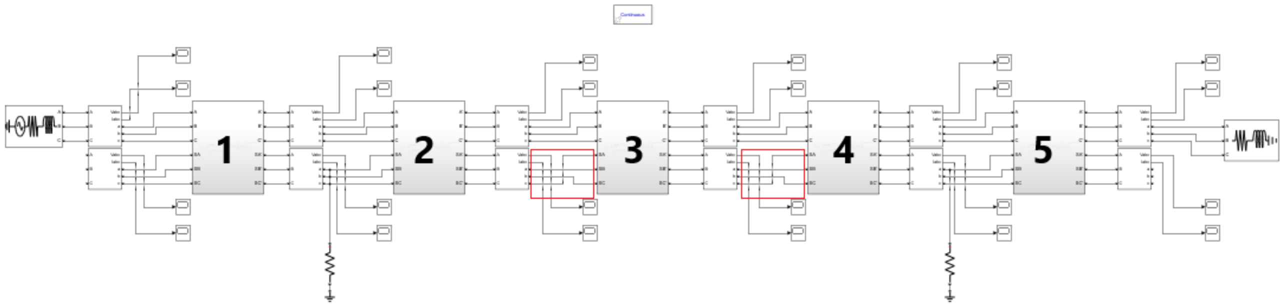

Fig. 10. Simulink model – Case 3.

With this configuration, almost no currents flow through the single-boned sheaths of the phase conductors "A" and "C" (Fig. 11), while at phase conductor "B", where the sheath was solidly bonded, a sheath current lower than those identified in Case 2 is present (Table V). This configuration is therefore potentially the most effective for the line analyzed.

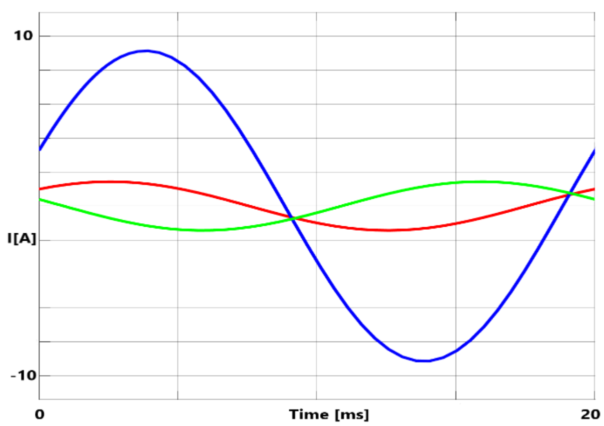

Fig. 11. Sheath currents - Case 3.

TABLE V
PEAK AND RMS VALUE OF THE SHEATH CURRENTS IN THE CASE 3.

	Sheath currents	
	Peak value [A]	RMS value [A]
Isa	1.4	1
Isb	9.1	6.4
Isc	1.4	1

IV. SHEATH LOSS ANALYSIS

Proceeding with the calculation of the power losses along the sheaths, a comparison is made between the above three cases. For this study, a segment of cable of length equal to 1 m is considered. In reference to the cable of Table II, the following resistive values are obtained:

- Conductor resistance: $R_{core} = 2.83 \cdot 10^{-5} \Omega$;
- Sheath resistance: $R_{sheath} = 2.3 \cdot 10^{-4} \Omega$.

This yields:

- Power losses in the conductors:

$$\Delta P_{core} = R_{core} \cdot (I_a^2 + I_b^2 + I_c^2);$$

- Power losses in the sheaths:

$$\Delta P_{sheath} = R_{sheath} \cdot (I_{sa}^2 + I_{sb}^2 + I_{sc}^2);$$

- Percentage power losses in the sheaths:

$$\Delta P_{sheath}\% = 100 \cdot \frac{\Delta P_{sheath}}{\Delta P_{core}}.$$

The power dissipated in the above three cases are shown in Table VI. For better comparing the three cases, it was assumed,

TABLE VI
POWER LOSS ANALYSIS.

	$\Delta P_s\%$
Case 1	798.94
Case 2	2.03
Case 3	0.053

From this analysis, it can be seen how, going from Case 2 to Case 3, a considerable reduction in the losses occurs, therefore the single-sheath bonding configuration is remarkably the most effective.

V. EXPERIMENTAL VALIDATION

The major drive for this research came from Prysmian Electronics and from the results of measurements performed on a 380 kV- 1500A- cable line in Northern Italy.

The line is realized with 2,500 mm^2- RE4H5E-380 kV single-core cables (Fig. 12), has a length of about 1.5 km and the distance between cables is about 20 cm. The cable is typically used in Italy for underground applications [23].

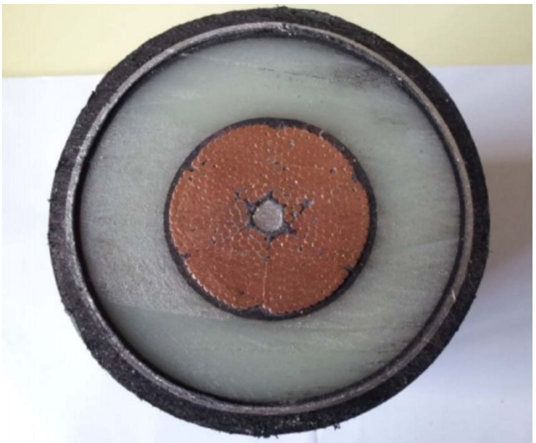

Fig. 12. 2500 mm^2- Single-core XLPE RE4H5E cable for 380kV systems [23].

In the presence of 5 minor sections and cross-bonding, sheath currents of tens of amperes were measured when the line was carrying a current close to its rated capacity. These sheath currents were able to generate a significant thermal stress on the cable, due to sheaths power losses that resulted in a dramatic reduction in the cables ampacity. Thus, a research was promoted to assess how the parameters of the cables and their installation could impact the sheath currents, which led to the definition of the model presented in this paper.

As reported in the previous sections, the model is based on the well-known Carson's theory, usually adopted for representing cables and overhead lines with lumped parameters models for steady-state analysis. A first validation of the simulation model was performed by analyzing a perfectly balanced line with the following characteristics:

- number of minor sections equal or multiple of three;
- equal length of the minor sections;
- routing of cables at the ends of an equilateral triangle;
- equal lengths of the cables of the three phases.

The simulations, as expected, provided very low sheath currents.

In addition, all the cross-bonding configurations described in IEEE 575-2014 [10] were simulated and the voltages induced on the sheaths obtained with the formulas provided by Annex E and F of [10] were compared with those obtained by applying the model presented in the paper, giving the same results. This has allowed the theoretical validation of the model.

The model was then used to implement in Matlab/Simulink and study the 380 kV- 1,500 A cable line at almost full operating load, with an average current of 1,470 A (r.m.s. value) circulating in the phase conductors. The currents in the fifth minor section were measured by Prysmian and then compared with the currents simulated using the presented model. The comparison with the error calculation is reported in Table VII.

TABLE VII
RMS VALUE OF THE SHEATH CURRENTS.

	Simulated values [A]	Measured values* [A]	Error [%]
Isa	51	41-50	7%-12%
Isb	38		
Isc	44		
* range of variations of the measured currents			

The comparison for the case study shows errors in the range of 7-12% that can depend on various factors: constructive differences in the cables, presence of localized resistances in cable joints, and differences in the lengths of the cables of the same minor section due to bends in the cable route.

The magnitude of the potential error is deemed acceptable, since the model is to be used for a rough estimation of sheaths currents during the design stage, and for testing various possible bonding configurations. Therefore, more accurate values are unnecessary.

VI. CONCLUSIONS

In this paper, the authors have presented a circuit model implemented in Matlab/Simulink for the calculation of the sheath currents in MV and HV distribution lines in the presence of different cross-bonding configurations. The model has been implemented for a real existing line and field validated. Simulations have shown that even under normal operating conditions the cable sheaths are subjected to considerable currents. For this reason, an analysis of possible solutions has been carried out to identify strategies to limit sheath currents. With this in mind, different types of sheath connections have been studied in order to identify the one with the lowest sheath current.

Finally, a study was carried out to analyze sheath power losses, and it has been verified that the type of connection used in case 3 ensures the lowest power loss.

The simulation model proposed in this paper may be used for steady-state analysis in the design stage to identify the sheath connection that allows the lowest sheath currents. the simulation may also be used during normal operations of the cable system to assess the values of the sheath currents in the case of load variation, so as to avoid reduction in the cable ampacity due to an increased temperature.

For transient analysis, more complex expressions of the impedance and admittance parameters of the cables must be adopted, as suggested by [23]-[24], in particular, for cable lying in metallic trays, which is a very common situation in industrial environment, and in the presence of high-order harmonic currents. In this case, the cross-bonding scheme adopted greatly influence the transient analysis and must be correctly represented to obtain reliable results [25]. The limitations of the proposed model for such transient studies will be assessed in future works.

ACKNOWLEDGEMENT

This work has been carried out within the framework of the International Research Agreement titled "*Innovative Solutions for Safety in Power Systems*," between the University of Palermo (Italy) and the Irvine Valley College (USA).

REFERENCES

[1] M. L. Di Silvestre, L. Dusonchet, S. Favuzza, S. Mangione, L. Mineo, M. Mitolo, E. Riva Sanseverino, G. Zizzo. "On the Interconnections of HV–MV Stations to Global Grounding Systems", *IEEE Transactions on Industry Applications, vol. 55(2), 2019, pp. 1126-1134.*

[2] G. Ala, S. Favuzza, E. Francomano, G. Giglia, G. Zizzo. "On the Distribution of Lightning Current among Interconnected Grounding Systems in Medium Voltage Grids", *ENERGIES, vol. 11(4), 2018, article 771.*

[3] *Requirements for Electrical Installations - IET Wiring Regulations, Eighteenth Edition*. Standard BS 7671:2018.

[4] I. Lafaia, J. Mahseredjian, A. Amentani, M. T. Correia de Barros, I. Koçar, Y. Fillon "Frequency and Time Domain Responses of Cross-Bonded Cables", *IEEE Transaction On Power Delivery, vol. 33(2), 2018, pp. 640-648.*

[5] Y. Zhang, X. Chen, Y. Qian, Z. Li, G. Sheng and X. Jiang, "Simulation Study and Detection Position Analysis on Position of Partial Discharge Detection in XLPE Cable Cross-bonding System", 2018 Condition Monitoring and Diagnosis (CMD), 23-26 September 2018, Perth (Australia)

[6] B. Sheng, C. Zhou, X. Dong, D. M. Hepburn, B. Alkali, W. Zhou, "Pd Detection And Localisation In Cross-Bondend HV Cable Systems", 22nd International Conference on Electricity Distribution, Paper 0129, 10-13 June 2013, Stockholm (Sweden).

[7] W. Wang, C. Liu, Z. Wang, C. F. Gao, H. Sui, "Application of capacitor sensor in PD detection at three-phase cross-bonding link-system of XLPE Cable", 2010 Annual Report Conference on Electrical Insulation and Dielectric Phenomena, 17-20 October 2010.

[8] M. Li, W. Zhou, C. Wang, L. Yao, C. Zhou, "A Novel Fault Localization Method Based on Monitoring of Sheath Current in a Cross-bonded HV Cable System", 2017 Electrical Insulation Conference (EIC), 11 - 14 June 2017, Baltimore (USA).

[9] Y. Lin, Z. Xu, "Cable Sheath Loss Reduction Strategy Research Based on the Coupled Line Model", *IEEE Transaction On Power Delivery, vol. 30(5), 2015, pp. 2303-2311.*

[10] IEEE Standard 575, 2014: *IEEE Guide for Bonding Shields and Sheaths of Single-Conductor Power Cables Rated 5 kV Through 500 kV.*

[11] A. Campoccia, L. Mineo, G. Zizzo, "A Method to Evaluate Voltages to Earth During an Earth Fault in an HV Network in a System of Interconnected Earth Electrodes of MV/LV Substations", *IEEE Transactions on Power Delivery, vol. 23(4), 2008, pp. 1763-1772.*

[12] M. A. Shokry, A. Khamlichi, F. Garnacho, J. Martinez, F. Álvarez, "Detection and Localization of Defects in Cable Sheath of Cross-Bonding Configuration by Sheath Currents", *IEEE Transaction On Power Delivery, vol. 34(4), 2019, pp. 1401-1411.*

[13] R. Candela, A. Gattuso, M. Mitolo, E. Riva Sanseverino, G. Zizzo, "A Model for the Study of Sheath Currents in Medium Voltage Cables for Industrial Application", 56th IEEE Industrial & Commercial Power Systems (I&CPS) Technical Conference, 2020, virtual conference.

[14] P. Moghe, F. de León, "Parametric Study of Losses in Cross-Bonded Cables: Conductors Transposed Versus Conductors Nontransposed", *IEEE Transaction On Power Delivery, vol. 28(4), 2013, pp. 2273-2281..*

[15] Y. Yang, D. M. Hepburn, C. Zhou, W. Jiang, B. Yang, W. Zhou, "On-line Monitoring and Trending of Dielectric Loss in a Cross-bonded HV Cable System", 2015 IEEE 11th International Conference on the Properties and Applications of Dielectric Materials (ICPADM), 19-22 July 2015, Sidney (Australia).

[16] L. Li, J. Yong, W. Xu, "Single Sheath Bonding – A New Method to Bond/Ground Cable Sheaths", *IEEE Transactions on Power Delivery, vol. 5(2), 2020, pp. 1065-1068.*

[17] J. R. Carson, "Wave Propagation in Overhead Wires with Ground Return", *Bell Systems Technical Journal, vol. 5, 1926, pp. 539–554.*

[18] IEEE Standard 367, IEEE Recommended Practice for Determining the Electric Power Station Ground Potential Rise and Induced Voltage from a Power Fault.

[19] IEC Standard 60909-3, Short-circuit currents in three-phase a.c. systems – Part 3: currents during two separate simultaneous line-to-earth short circuits and partial short-circuits currents flowing through earth.

[20] M. S. Stojanovic, D. D. Tasic, N. N. Cvetkovic, D. B. Jovanovic, D. D. Vuckovic, "Self and Mutual Impedances of Power Cables", ICEST 2017, 28-30 June 2017, Nis (Serbia).

[21] J. C. Jr. Parker, "Hand Held Calculator Program for Evaluating External Mutual Impedance," Bell Laboratories Technical Memorandum, Feb. 1980.

[22] E. J. Rogers, J. F. White, "Mutual coupling between finite lengths of parallel or horizontal earth return conductors", *IEEE Transactions on Power Delivery, vol. 4(1), 1989, pp. 103-13.*

[23] R. Benato, S. Dambone Sessa, R. De Zan, M. R. Guarniere, G. Lavecchia, P. Sylos Labini, "Different Bonding Types of Scilla–Villafranca (Sicily–Calabria) 43-km Double-Circuit AC 380-kV Submarine–Land Cables", *IEEE Transactions on Industry Applications, vol. 51(6), 2015, pp. 5050-5057.*

[24] W. L. de Souza, H. de Paula, A. De Conti, R. C. Mesquita, "Cable Parameter Calculation for Typical Industrial Installation Methods and High-Frequency Studies", *IEEE Transactions on Industry Applications, vol. 54(4), 2018, pp. 3919-3927.*

[25] A. Ametani, N. Nagaoka, Y. Baba, T. Ohno, K. Yamabuki, "Transients on Cable Systems" from: Power System Transients, Theory and Applications, 2016, CRC Press, available at: https://www.routledgehandbooks.com/doi/10.1201/9781315366791-4, Accessed on: 22 May 2020.

Roberto Candela received the doctor's degree in electrical engineering at the University of Palermo, Italy, in 1996. Since 1996, he has been with the Research Group of Electrotechnics at the University of Palermo. Since December 2004, he has been a Researcher with the University of Palermo, where he teaches basic electrical engineering and electrotechnics and foundations of informatics. His research interest include the optimization methods for diagnosis in dielectrics material for high voltage application and development of technologies for the signals treatment and diagnosis of insulating system through partial discharges measurements. In 2006, he developed and patented a new sensor for measuring partial discharges in wireless mode that is on the base of Pry-Cam product range. Since 2012, he has been a CEO of Prysmian Electronics, Palermo, Italy, a company of Prysmian group, responsible worldwide for energy asset management systems.

Antonio Gattuso received the master's degree in Electrical Engineering in 2019 at the University of Palermo, Italy. In 2020 he started a collaboration with the Department of Engineering of the same University and Prysmian Electronics company. His current research interests include electrical safety, grounding systems, transmission and distribution power lines, cables' sheaths.

Massimo Mitolo (Fellow, IEEE) received the Ph.D. degree in electrical engineering from the University of Napoli "Federico II," Italy.,He is currently a Full Professor of electrical engineering with the Irvine Valley College, Irvine, CA, USA, and also a Senior Consultant in the matter of failure analysis and electrical safety with Engineering Systems Inc., ESi. He has authored over 140 journal papers and books, including the "Electrical Safety of Low-Voltage Systems" (McGraw-Hill), the "Laboratory Manual for Introduction to Electronics: A Basic Approach" (Pearson), and the "Analysis of Grounding and Bonding Systems" (CRC Press). His research interests include the analysis and grounding of power systems and electrical safety engineering.,Dr. Mitolo is a Fellow of the IEEE in recognition "for contributions to the electrical safety of low-voltage systems," and a Fellow of the Institution of Engineering and Technology (IET) of London. He is a registered Professional Engineer in the state of California and in Italy. He is active within the Industrial and Commercial Power Systems Department of the IEEE Industry Applications Society (IAS) in numerous committees and working groups. He is a recipient of the James E. Ballinger Engineer of the Year 2013 Award from the Orange County Engineering Council. He has received numerous recognitions and best paper awards, among which are the IEEE "Ralph H. Lee I&CPS Department Prize Paper Award," the IEEE "I&CPS 2015 Department Achievement Award," and the IEEE Region 6 "2015 Outstanding Engineer Award." He currently serves both as an Associate Editor and a Guest Editor for the IEEE IAS Transactions. He is currently the Deputy Editor-in-Chief of the IEEE Transactions on Industry Applications.

Eleonora Riva Sanseverino received the master's degree in electrical engineering from the University of Palermo, Italy, in 1995, and the Ph.D. degree in electrical engineering, in 2000. She has been an Associate Professor of electrical power systems with the University of Palermo, since 2002, where she has also been a Full Professor, since November 2019. She is currently a scientific coordinator of various research projects with research organizations and companies. She is also responsible of various research and teaching cooperation agreements with foreign institutions and private companies. These include European institutions Aalborg University, Denmark, Chalmers University of Technology, Sweden, and extra-European institutions, such as Electric Power University and the Institute of Energy Science both in Hanoi, Vietnam. She has authored more than 250 articles on international journals, edited books and book chapters, and conference proceedings. She is the Editor in Chief of the UNIPA Springer Series. She is also the Coordinator of the Ph.D. in Energy with the University of Palermo.

Gaetano Zizzo (SM'17) is Associate Professor of Electrical Power Systems at the University of Palermo, Italy, where he obtained his M.S. degree in 2002 and his Ph.D. degree in Electrical Engineering in 2006. Since 2006 he works at the Engineering Department of the same university. In 2017 he was elected Senior Member IEEE as a member of the Industry Application Society. He is involved in the activities of the IEEE Standard Association. His current research interests include electrical safety, power systems design, management, and optimization, smart grids and stability analysis.