A proposed method for reduction of induced zero-sequence current in cable system

Shimaa Abdel-Raouf Salem[1], Rabab Reda Eiada[2], Ebrahim Abdel-Ghafar Badran[3]
[1]North Delta Electric Distribution Company (NDEDC), Mansoura, Egypt
[2]New Damietta High Institute of Engineering and Technology, Ministry of High Education, New Damietta, Egypt
[3]Electrical Engineering Department, Faculty of Engineering, Mansoura University, Mansoura, Egypt

Article Info

Article history:

Received Aug 1, 2022
Revised Sep 12, 2022
Accepted Sep 27, 2022

Keywords:

Cables arrangement
Cables transposition
Current distribution
Sheath cross bonding
Zero-sequence currents

ABSTRACT

Zero-sequence circulating currents are particularly problematic because they can occasionally lead to protective relay failure. However, it is not usually understood that systems with numerous cables strung along the same path will produce zero-sequence currents. In this paper, the operation of parallel connections of single core underground cables is examined. The examination is based on power cables arrangement operating in parallel two-circuit with and without the transmission grid. It was found that symmetrical cable arrangement might significantly lower zero-sequence currents in a twin-circuit. On the other hand, the largest value of the zero sequence currents at asymmetrical configuration. To provide an effective method about reduction of zero sequence current induced in a cable system, several connection scenarios such as the transposition of the cable and sheath and the application of sheath cross bonding are examined. Therefore, in this paper, this phenomenon will be analyzed and discussed. ATPDraw is used to simulate and analysis this kind of study. Also, the effect of sheath transposition is explained and analyzed.

Corresponding Author:

Shimaa Abdel-Raouf Salem
North Delta Electric Distribution Company (NDEDC), Mansoura, Egypt
Email: shimaa.ammar89@gmail.com

1. INTRODUCTION

Single-core power cables are being used more and more frequently as a result of the Smart Power Bulk Transmission Systems' quick development. The cable's metal sheath experiences additional loss as a result of the circulating current that is generated on it, which reduces the length of time that the cable will operate safely. Studies and analysis were done on the variations in circulating current on the metal sheath of single-core cables under various load circumstances and arrangements [1]–[6]. Depending on the overall cable size, the currents in the outermost layers of bundled cables were at least four times higher than those in the innermost layers. The adverse effects of the unbalanced current were reduced If single conductor cables were placed in a symmetrical arrangement or arranged in a "triangular" arrangement if three, five, or six cables were required in each phase [7]–[24].

Large zero-sequence current (I_{ZS}) is not a new phenomenon for cable bus duct systems; the question is what influences its magnitude. It is well known that I_{ZS} flows via each circuit of lines when several circuits are installed on a single tower. Particularly problematic are I_{ZS} because they can occasionally lead to protective relay failure. It was found that the zero-sequence currents were circulating between different circuits in the cable system and that they were being generated by induction between phases in the same cable route. Depending on the cable configuration, such as that of an untransposed line, the impedance imbalance between the phases cannot be ignored [25]–[28].

Using the alternative transients program (ATP)/electromagnetic transients program (EMTP) software, the induced sheath voltages and currents in a three-phase MV SC cable were computed for steady-state and fault scenarios [29]. To keep the induced sheath voltages below the allowable values and to maintain low sheath currents and subsequently low losses, the effects of grounding, cross bonding, and transposition techniques as well as the number of joint points are explored. It was further demonstrated that the induced voltages and currents were proportional to the length of the cable and could only be decreased by using cross bonding and transposition techniques in addition to grounding the cable ends [30]–[33]. According to the current theory, the transposition of transmission line phases is meant to reduce the current and voltage imbalance in the electric system's normal operating mode and to prevent transmission lines from obstructing low-frequency transmission channels [34]. In normal operation, the sheath adopts cross connected grounding, which reduces induced currents and allows for the energy loss brought on by induced currents to be disregarded. In actual engineering, there will still be residual positive and negative sequence current in each phase of the sheath after complete transposition since the length of each section of cables is not consistent [35], [36].

In this paper, the I_{ZS} was recently discovered to be flowing in an unexpectedly large amount in a cable system. A test power system is used for this study's analysis of the zero-sequence currents using the alternative transient program (ATP). It is demonstrated that the ATPDraw software is effective at analyzing I_{ZS} produced in a system of cables [37]. A typical two-circuit cable system is examined using the ATP diagram to show that large I_{ZS} are induced in the cable systems. It is shown that the currents are changed dramatically according to the arrangement of each cable. When reducing zero-sequence currents, various layouts are examined in light of their underlying physical causes. Also, a proposed method for reduction of I_{ZS} induced in a cable system is introduced and discussed.

2. METHOD

2.1. Test system description

The simulate system consists of one main cross bonded cable section and three smaller parts, each measuring 250 m. According to the test system, the simulated system's voltage class is set at 77 kV. A 77 kV/1000 mm^2 XLPE cable is used. Table 1 shows the cable parameters [38]. While taking conductor and sheath into account, each minor section is represented by a PI equivalent circuit's single section. Both of the cable's sheaths are grounded by a 10-ohm resistor and are short circuited at both ends. The load is represented by 44.5 ohm, three-phase, and star-connections. The load is balanced, star-connection resistor. It is not earthed at the load's neutral point.

Table 1. Parameters of 77 kV, 1000 mm^2 XLPE cable

Type of cable	Single core,1000 mm^2 XLPE
Outer core diameter	38 mm
Inner sheath diameter	57.3 mm
Overall diameter	79 mm
Resistivity of core	1.7E-8 Ω.m
Resistivity of sheath	2.5E-8 Ω.m

2.2. Test system simulation with and without transposition for two-circuit

To study I_{ZS} in a two-circuit system, the test system is modeled using ATPDraw as shown in Figure 1. An extraction of the fundamental I_{ZS} can be performed according to (1)-(3) [39].

$$\begin{bmatrix} i_{ap} \\ i_{bp} \\ i_{cp} \end{bmatrix} = \frac{1}{3}\begin{bmatrix} i_a - \frac{1}{2}(i_b + i_c) + j\frac{\sqrt{3}}{2}(i_b - i_c) \\ -(i_{ap} + i_{cp}) \\ i_c - \frac{1}{2}(i_a + i_b) + j\frac{\sqrt{3}}{2}(i_a - i_b) \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} i_{an} \\ i_{bn} \\ i_{cn} \end{bmatrix} = \frac{1}{3}\begin{bmatrix} i_a - \frac{1}{2}(i_b + i_c) + j\frac{\sqrt{3}}{2}(i_b - i_c) \\ -(i_{ap} + i_{cp}) \\ i_c - \frac{1}{2}(i_a + i_b) + j\frac{\sqrt{3}}{2}(i_a - i_b) \end{bmatrix} \quad (2)$$

$$\begin{bmatrix} i_{a0} \\ i_{b0} \\ i_{c0} \end{bmatrix} = \frac{1}{3} \begin{bmatrix} (i_a + i_b + i_c) \\ (i_a + i_b + i_c) \\ (i_a + i_b + i_c) \end{bmatrix} \quad (3)$$

Where i_a, i_b, and i_c are the measured phase currents for phase A, B, and C, respectively. Also, i_{ap}, i_{bp}, and i_{cp} are three-phase positive sequence components; i_{an}, i_{bn} and i_{cn} are three-phase negative sequence components, and i_{a0}, i_{b0}, and i_{c0} are three-phase zero-sequence components for the three-phases, respectively. The ATPDraw model of the currents calculations given in (1) to (3) is illustrated in Figure 2.

In case (10) each cable and sheath are transposed using all types of transposition (ABC-BCA, ABC-CAB, ABC-CBA and ABC-ACB) to find the best type of transposition and apply it to all study cases. Figure 3 shows the test system model in ATP Draw with cable and sheath transposition. Different cable configurations in the model system of a twin-circuit in parallel are given as shown in Table 2 (case 1 to case 11) as follow:

- Low reactance phasing (LR phasing) is a type of phasing arrangement where cases (1) and (2) are arranged in reverse, and case 1 is an arrangement where there is no conduit between L1 and L2.
- Super-bundle phasing (SB phasing) is used to describe cases (3) and (4), and case (3) is the arrangement where the conduit line between L1 and L2 is left empty of cases (4).
- The definitions of cases (5) and (6) are a triangular configuration of L1 and L2 and a point symmetric to the centre of six cables.
- In case (7), a diagonal-shaped empty conduit line is formed by the arrangement of L1 and L2, which are triangularly arranged and axially symmetrical to it.
- The asymmetrical cable configurations between circuits L1 and L2 are represented by Cases (8) to (10) in the model.
- In cases 10 and 11, an underground cable that is directly buried and axially symmetrical is assumed.

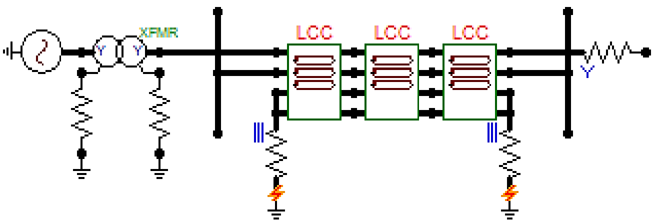

Figure 1. The twin-circuit system model in ATPDraw without transposition

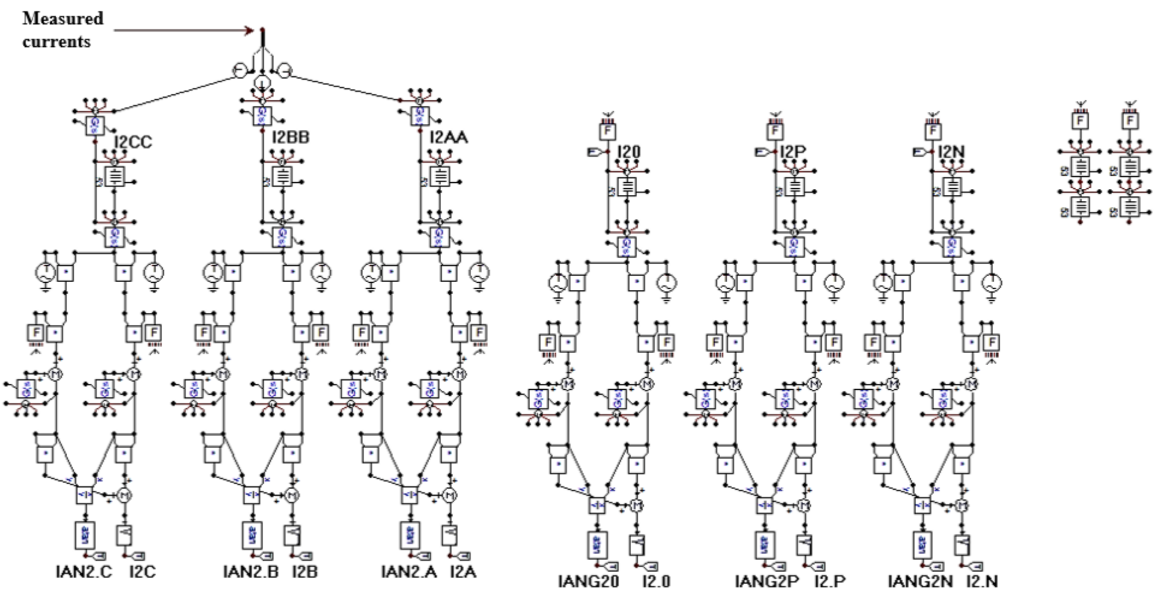

Figure 2. ATPDraw model for currents calculations

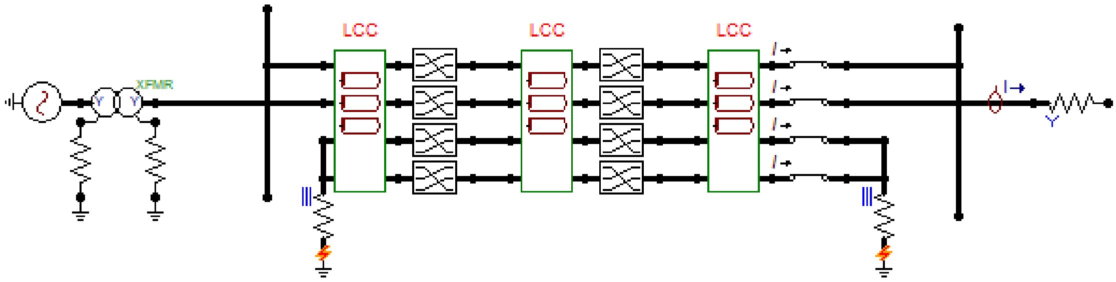

Figure 3. System model in ATP Draw in a twin-circuit with cable and sheath transposition

Table 2. Various cable arrangements for a twin circuit (take A1 reference)

Case		Cable					
		a1	b1	c1	a2	b2	c2
Case 1	V	1.6	1.83	2.06	1.6	1.83	2.06
	H	0	0	0	0.46	0.46	0.46
Case 2	V	1.6	1.83	2.06	2.06	1.83	1.6
	H	0	0	0	0.23	0.23	0.23
Case 3	V	1.6	1.83	2.06	1.6	1.83	2.06
	H	0	0	0	0.46	0.46	0.46
Case 4	V	1.6	1.83	2.06	1.6	1.83	2.06
	H	0	0	0	0.23	0.23	0.23
Case 5	V	1.83	2.06	2.06	1.83	1.6	1.6
	H	0	0	0.23	0.46	0.46	0.23
Case 6	V	1.6	1.83	1.83	1.83	1.6	1.6
	H	0	0	0.23	0.46	0.46	0.23
Case 7	V	1.83	2.06	2.06	1.6	1.6	1.83
	H	0	0	0.23	0.23	0.46	0.46
Case 8	V	1.6	1.83	1.83	1.6	1.6	1.83
	H	0	0	0.23	0.23	0.46	0.46
Case 9	V	1.6	1.83	2.06	2.06	1.83	1.6
	H	0	-0.23	-0.23	0.23	0.23	0.23
Case 10	V	1.6	1.6	1.6	1.6	1.6	1.6
	H	0	0.23	0.46	0.69	0.92	1.15
Case 11	V	1.6	1.6	1.6	1.6	1.6	1.6
	H	0	0.23	0.46	1.15	0.92	0.69

3. RESULTS AND DISCUSSION

3.1. Analysis of Izs without transposition

Figure 4 shows the results of I_{ZS} for cases (1) to (11). Table 3 gives the results of I_{ZS} for all cases. It is noted from Table 3 that low I_{ZS} flows with symmetrical cable configuration (1) to (7) and (11). However, for the asymmetrical cable configuration (8) to (10), I_{ZS} of 144 to 178 A flow for the same load currents. Math analysis of the parallel two-circuit cases proves the required condition to insure no I_{ZS} is to have all mutual impedance's between conductors balanced [26]. Proper conductor phasing arrangements can accomplish this. A zero I_{ZS} condition corresponds to point or axial symmetry of the six-conductors in the two parallel circuits and indicates an asymmetrical cable configuration is the cause of I_{ZS} generation. To put it another way, the I_{ZS} in the twin circuit is produced by the mutual impedance unbalance.

3.2. Analysis of the reduction of I_{ZS} by using transposition on cable and sheath

The results of I_{ZS} in a twin circuit with cable and sheath transposition of all types of transposition (ABC-BCA, ABC-CAB, ABC-CBA and ABC-ACB) for case (10) is (39.086 A, 39.093 A, 59.221 A and 151.22 A) respectively. It is observed from the results that the better type of transposition is ABC-BCA type, so it is applied to all study cases. In a twin-circuit system the arrangements (8) to (10) where the highest I_{ZS}

flows, are used to study the influence of cable and sheath transposition over I_{ZS}. Table 4 gives the results of I_{ZS} with cable and sheath transposition in a twin circuit. It is observed from the results that the I_{ZS} ratio is reduced by 79%, 77% and 78% respectively.

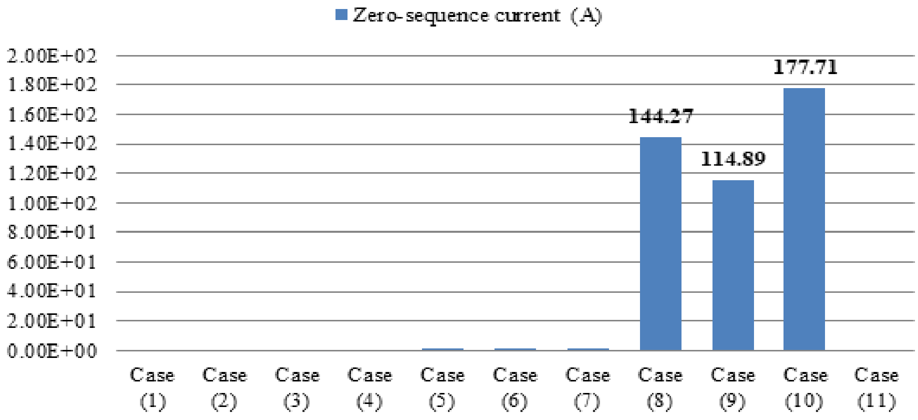

Figure 4. The calculated I_{ZS} in twine-circuit for all cases

Table 3. Results of I_{ZS} in twin circuit

Arrangement	Zero sequence current (A)	Arrangement	Zero sequence current (A)
Case (1)	2.0343E-5	Case (7)	1.8486E-3
Case (2)	8.2310E-6	Case (8)	144.27
Case (3)	4.6838E-8	Case (9)	114.89
Case (4)	5.8053E-8	Case (10)	177.71
Case (5)	1.6198E-4	Case (11)	1.0256E-7
Case (6)	1.6573E-4		

Table 4. Results of Izs in a twin circuit with cable and sheath transposition

Arrangement	Zero sequence current (A) with transposition
Case (8)	30.135
Case (9)	26.635
Case (10)	39.086

3.3. Effect of sheath crossbonding

The arrangements of case (4), which has no I_{ZS} flowing, and case (8), which has the maximum I_{ZS} flowing, are taken from Table 3 in order to analyze the effect of sheath cross bonding over I_{ZS} in twin-circuit systems. Additionally, calculations were done for two scenarios: balanced cross bonding (each minor section was 250 m long) and unbalanced cross bonding (1ength of minor section at 300-250-200 m). This section analyses and discusses the findings of a study on how sheath cross bonding affects I_{ZS} in twin-circuit systems.

The calculated results for I_{ZS} in twin-circuit systems for different cable configurations are shown in Table 5. The table shows that, assuming balanced cross bonding is used, the sheath current at the arrangement of case (8) of big I_{ZS} is approximately ten times greater than that by configuration of case (4) of no I_{ZS}. However, the I_{ZS} in the circuit of unbalanced cross bonding is not affected by the cable arrangement. However, in the design of case (8) where the I_{ZS} is considerable, the sheath circulation current between circuits is practically constant, at roughly 24 A, and irrespective of the imbalance ratio. While no sheath current circulates in the configuration of case (4).

Case (8) is taken to analyze the effect of transposition over I_{ZS}. Table 6 gives a comparison between results of I_{ZS} for balanced cross bonding without transposition, balanced cross bonding with transposition and unbalanced cross bonding with transposition in a twin-circuit system for cable arrangements case (8). In the circuit of balanced cross bonding, however, the I_{ZS} in cable and sheath are decrease by cable and sheath transposition. In other hand the circuit of unbalanced cross bonding, however, the I_{ZS} in cable and sheath are higher than the circuit of balanced cross bonding by cable and sheath transposition as shown in Figure 5.

Table 5. The results of Izs for sheath crosbonding

Cases	Cable	Arrangement (4)		Arrangement (8)	
		Conductor (A)	Sheath (A)	Conductor (A)	Sheath (A)
Balanced cross bonding	L1	5.8053E-8	0.62323	144.27	23.865
	L2	5.8053E-8	0.62323	144.27	23.865
Unbalanced cross bonding	L1	5.8126E-8	0.62323	144.27	23.865
	L2	5.8126E-8	0.62323	144.27	23.865

Table 6. Results of Izs for cable and sheath cross bonding

Cases	Cable	Arrangement (8)	
		Conductor (A)	Sheath (A)
Balanced cross bonding without transposition	L1	144.27	23.865
	L2	144.27	23.865
Balanced cross bonding with transposition	L1	26.635	4.9865
	L2	26.635	4.9865
Unbalanced cross bonding with transposition	L1	39.523	6.5367
	L2	39.523	6.5367

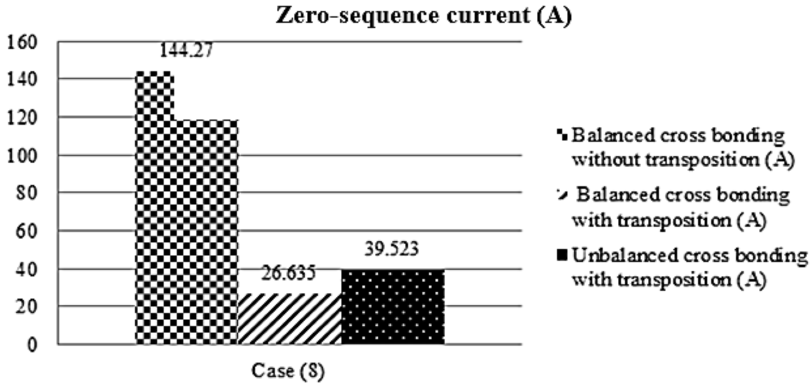

Figure 5. A comparison between I_{ZS} for balanced cross bonding without transposition, balanced cross bonding with transposition and unbalanced cross bonding with transposition in a twin-circuit system for cable arrangements case (8)

4. CONCLUSION

This paper uses ATPDraw to simulate and analysis the I_{ZS} generated in cable systems. In order to decrease the mutual coupling imbalance, which in turn reduces the I_{ZS}, cable arrangements are studied. It has been discovered that choosing the ideal cable configuration practically reduces the I_{ZS}. The results demonstrate that the transposition of cable and sheath in parallel-two-circuits reduces the amplitude of I_{ZS} induced in the cable system. The following conclusions were drawn: i) In a twin-circuit system, a I_{ZS} circulates between two circuits of cables and is lowered to almost zero with a symmetrical phase configuration; ii) The transposition of the cable and sheath reduces the I_{ZS} of cables by around 77%; iii) The I_{ZS} is not significantly affected by any unbalanced cross bonding, but it is increased using the transposition of the cable and sheath via unbalance cross bonding of the cable; and iv) The I_{ZS} current is reduced by about 83% using a transposition of the cable and sheath with balance cross bonding of the cable in a twin -circuit system.

REFERENCES

[1] Z. Li, B. X. Du, L. Wang, C. Yang, and H. J. Liu, "The calculation of circulating current for the single-core cables in Smart Grid," *2012 IEEE Innov. Smart Grid Technol. - Asia, ISGT Asia 2012*, pp. 1–4, 2012, doi: 10.1109/ISGT-Asia.2012.6303176.

[2] C. G. Kaloudas, T. A. Papadopoulos, K. V. Gouramanis, K. Stasinos, and G. K. Papagiannis, "Methodology for the selection of long-mediumvoltage power cable configurations," *IET Gener. Transm. Distrib.*, vol. 7, no. 5, pp. 526–536, 2013, doi: 10.1049/iet-gtd.2012.0165.

[3] M. Shaban, M. A. Salam, S. P. Ang, and W. Voon, "Induced sheathvoltageinpowercables:Areview," *Renew. Sustain. Energy Rev.*, vol. 62, pp. 1236–1251, 2016, doi: 10.1016/j.rser.2016.05.032.

[4] M. Rasoulpoor, M. Mirzaie, and S. M. Mirimani, "Electrical and thermal analysis of single conductor power cable considering the lead sheath effect based on finite element method," *Iran. J. Electr. Electron. Eng.*, vol. 12, no. 1, pp. 73–81, 2016, doi: 10.22068/IJEEE.12.1.73.

[5] B. Akbal, “Sectional Solid Bonding for Grounding of High Voltage Underground Cables to Reduce the Sheath Current Effects,” *Int. J. Innov. Res. Eng. Manag.*, no. 2, pp. 103–107, 2016.
[6] B. Akbal, “OSSB and hybrid methods to prevent cable faults for harmonic containing networks,” *Elektron. ir Elektrotechnika*, vol. 24, no. 2, pp. 31–36, 2018, doi: 10.5755/j01.eie.24.2.20633.
[7] A. Y. Wu, “Single-Conductor Cables in Parallel,” *IEEE Trans. Ind. Appl.*, vol. IA-20, no. 2, pp. 377–395, 1984, doi: 10.1109/TIA.1984.4504423.
[8] A. A. Ghandakly and R. L. Curran, “A Model to Predict Current Distributions in Bundled Cables for Electric Glass Melters,” *IEEE Trans. Ind. Appl.*, vol. 26, no. 6, pp. 1043–1048, 1990, doi: 10.1109/28.62385.
[9] F. De León, “Major factors affecting cable ampacity,” *IEEE*, vol. 8, pp. 1–6, 2006, doi: 10.1109/pes.2006.1708875.
[10] Y. Du, Y. Z. Yuan, and X. H. Wang, “Current distribution in parallel single-core cables on metal tray,” *IEEE Trans. Ind. Appl.*, vol. 44, no. 6, pp. 1886–1891, 2008, doi: 10.1109/TIA.2008.2006345.
[11] S. Y. Lee, “A cable configuration technique for the balance of current distribution in parallel cables,” *J. Mar. Sci. Technol.*, vol. 18, no. 2, pp. 290–297, 2010.
[12] B. Novák and L. Koller, “Current distribution and losses of grouped underground cables,” *IEEE Trans. Power Deliv.*, vol. 26, no. 3, pp. 1514–1521, 2011, doi: 10.1109/TPWRD.2011.2104980.
[13] F. Freschi and M. Tartaglia, “Power lines made of many parallel single-core cables: A case study,” *IEEE Trans. Ind. Appl.*, vol. 49, no. 4, pp. 1744–1750, 2013, doi: 10.1109/TIA.2013.2257979.
[14] Z. Li, X. Zhong, J. Xia, R. Bian, S. Xu, and J. Cao, “Simulation of current distribution in parallel single-core cables based on finite element method,” *Proc. - 5th Int. Conf. Instrum. Meas. Comput. Commun. Control. IMCCC 2015*, pp. 411–415, 2016, doi: 10.1109/IMCCC.2015.94.
[15] Z. Li, X. Zhong, J. Xia, R. Bian, S. Xu, and J. Cao, “Simulation of current distribution in parallel single-core cables based on finite element method,” in *2015 Fifth International Conference on Instrumentation and Measurement, Computer, Communication and Control (IMCCC)*, 2015, pp. 411–415.
[16] J. E. V. Fassarela, M. Z. Fortes, and G. G. Sotelo, “Measurement, evaluation and proposed solution for power distribution arrangements with electrical cables in parallel,” *Meas. J. Int. Meas. Confed.*, vol. 119, no. January, pp. 196–204, 2018, doi: 10.1016/j.measurement.2018.01.056.
[17] A. A. Ghandakly, R. L. Curran, and G. B. Collins, “Ampacity Ratings of Bundled Cables for Heavy Current Applications,” *IEEE Trans. Ind. Appl.*, vol. 30, no. 2, pp. 233–239, 1994, doi: 10.1109/28.287539.
[18] F.P. Dawson; M. Cao; P.K. Jain, “A simplified approach to calculating current distribution in parallel power buses,” *IEEE Trans. Magn.*, vol. 28, no. 8, pp. 40–43, 1990.
[19] K. A.Petty, “Calculation of current division in parallel single-conductor power cables for generating station applications,” *IEEE Trans. Power Deliv.*, vol. 36, no. 1, pp. 964–968, 1989.
[20] Y. Du and J. Burnett, “Current distribution in single-core cables connected in parallel,” *IEE Proc. Gener. Transm. Distrib.*, vol. 148, no. 5, pp. 406–412, 2001, doi: 10.1049/ip-gtd:20010430.
[21] A. A. Al-Ohaly, K. F. Ali, and M. A. El-Kady, “An Improved Algorithm for Efficient Computation of Current Distribution in Power Cables,” *J. King Saud Univ. - Eng. Sci.*, vol. 14, no. 2, pp. 251–258, 2002, doi: 10.1016/S1018-3639(18)30757-8.
[22] H. Brakelmann, P. F. Deister, J. Roth, and M. Schuster, “Cable device for suppression of current displacements in parallel cables,” in *Proceedings 17th International Conference on Electricity distribution*, 2003, no. 1, pp. 12–15.
[23] C. D. K. Gouramanis, “Cable Overheating in an Industrial Substation Feeder Due to Untransposed Power Cables - Measurement and Simulation,” *IEEE Trans. Power Deliv. https//ieeexplore.ieee.org/xpl/conhome/10849/proceeding*, vol. 4, pp. 1438–1441, 2005.
[24] R. Natarajan and T. Hunger, “Investigations on three-phase current distribution in parallel cable conductors,” *Electr. Power Components Syst.*, vol. 33, no. 7, pp. 755–766, 2005, doi: 10.1080/15325000590896746.
[25] M. H. Hesse, “Circulating currents in paralleled untransposed multicircuit lines: I-numerical evaluations,” *IEEE Trans. Power Appar. Syst.*, no. 7, pp. 802–811, 1966.
[26] H. Nakanishi *et al.*, “A study of zero-sequence current induced in a cable system,” *IEEE Trans. Power Deliv.*, vol. 6, no. 4, pp. 1352–1358, 1991, doi: 10.1109/61.97663.
[27] G. L. Skibinski, B. Brown, and M. Christini, “Effect of cable geometry on induced zero sequence ground currents with high power converters,” *IEEE*, 2006, doi: 10.1109/PCICON.2006.359703.
[28] M. H. Hesse, “Circulating Currents in Paralleled Untransposed Multicircuit Lines: II—Methods for Estimating Current Unbalance,” *IEEE Trans. Power Appar. Syst.*, vol. PAS-85, no. 7, pp. 812–820, 1966, doi: 10.1109/TPAS.1966.291709.
[29] T. A. Papadopoulos, E. T. Makri, A. C. Dimou, A. I. Chrysochos, and G. K. Papagiannis, “An investigation of the performance of underground cable installations in operational and fault conditions,” in *8th Mediterranean Conference on Power Generation, Transmission, Distribution and Energy Conversion MEDPOWER 2012*, 2014, pp. 49–49. doi: 10.1049/cp.2012.2030.
[30] K. V. Gouramanis, C. G. Kaloudas, T. A. Papadopoulos, G. K. Papagiannis, and K. Stasinos, “Sheath voltage calculations in long medium voltage power cables,” *2011 IEEE PES Trondheim PowerTech Power Technol. a Sustain. Soc. POWERTECH 2011*, pp. 1–7, 2011, doi: 10.1109/PTC.2011.6019234.
[31] C. G. Kaloudas, T. A. Papadopoulos, K. V Gouramanis, G. K. Papagiannis, and K. Stasinos, “Simulation of Switching and Lightning Transients in Parallel Single-Core Underground Cables,” in *2011 46th International Universities’ Power Engineering Conference (UPEC)*, 2011, pp. 1–6.
[32] M. A. Shokry, A. Khamlichi, F. Garnacho, J. M. Malo, and F. Alvarez, “Detection and localization of defects in cable sheath of cross-bonding configuration by sheath currents,” *IEEE Trans. Power Deliv.*, vol. 34, no. 4, pp. 1401–1411, 2019, doi: 10.1109/TPWRD.2019.2903329.
[33] S. A. Ledari and M. Mirzaie, “Sheath induced voltage prediction of high voltage cable based on artificial neural network,” *Comput. Electr. Eng.*, vol. 87, no. July, p. 106788, 2020, doi: 10.1016/j.compeleceng.2020.106788.
[34] A. M. Gashimov, A. R. Babayeva, and A. Nayir, “Transmission line transposition,” in *2009 International Conference on Electrical and Electronics Engineering-ELECO 2009*, 2009, pp. I–364.
[35] A. Thankgod, D. Idoniboyeobu, and S. L. Braide, “Analysis Of Effects of Conductor Transposition on the 132kv Alaoji-Port Harcourt Transmission Line,” *IRE Transactions on Engineering Management*, vol. 5, no. 7, pp. 223-238 2022.
[36] J. Fang *et al.*, “110kV high voltage cable sheath transposition to reduce the grounding induction currents,” in *IOP Conference Series: Earth and Environmental Science*, 2022, vol. 983, no. 1, p. 12006.
[37] L. Prikler and H. K. Høidalen, “ATPDraw version 3.5 users’ manual,” *SINTEF Energy Res. Norw.*, 2002.
[38] S. A. Nexans, “6–36 kV Medium Voltage Underground Power Cables,” *https://www.powerandcables.com/wp-content/uploads/2016/12/Nexans-6-33kV-Medium-High-Voltage-Underground-Power-Cables.pdf*. p. 48, 2009.

[39] E. A. Badran and M. H. Abdel-rahman, "A Power Quality Detection Method for Grid-Connected Wind Farms," *Int. J. Power Eng. Green Technol.*, pp. 65–72, 2010.

BIOGRAPHIES OF AUTHORS

Shimaa Abdel-Raouf Salem received her BSc in 2011from the electrical power and machines department, Mansoura University, Egypt. She is currently technical affairs engineer with North Delta Electricity Distribution Company, Egypt. Her current research interests include power system distributed and generation. She can be contacted at email: shimaa.ammar89@gmail.com.

Rabab Reda Eiada was born in Egypt in 1980. She received her B.Sc., M.Sc. and Ph.D. in Electrical Engineering from Mansoura University, Egypt, in 2004 - 2009 and 2019, respectively. From 2004 to 2009 she was a research assistant in the Electrical Engineering Department, Mansoura University. In 2010-2019 she is an electricity engineer with the engineering management, Mansoura University, Egypt. She is currently a staff member of the High Institute of Engineering & Technology, New Damietta, Egypt. Her current research interests include power system Analysis, FACTs, distributed generation, and Renewable Energy. She can be contacted at email: rabab.reda@ndeti.edu.eg.

Ebrahim Abdel-Ghafar Badran was born in Egypt in 1969. He received his B.Sc., M.Sc. and Ph.D. in Electrical Engineering from Mansoura University, Egypt, in 1991, 1995 and 2004, respectively. From 1993 to 1999 he was an operation engineer with the Egyptian Electricity Authority. In 1999 he joined with the Academy of Special Studies, Egypt, where he is the Head of Technology Department from 2004 to 2008. He joined the Electrical Engineering department, University of El-Mansoura at 2008, where he is now a full professor. The research interests of Prof. Badran include Transients in Power System, Power System Protection, Modeling of Power System, Power Quality, FACTS, and Renewable Energy. He can be contacted at email: ebadran@mans.edu.eg.