

## Simulation of sheath voltage, losses and loss factor of high voltage underground cable using MATLAB/Simulink

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### ABSTRACT

In this paper, 22 equations for high voltage cable sheaths are simulated in one model. The model outputs are represented by cable sheath voltages, circulating currents, losses and factors, eddy currents, losses, and factors in both tides laying states (trefoil and flat) when grounding the sheaths from a single point, two points, or cross-link. These values depend on the cable manufacturing's specific factors. The other factors affecting these values are specific to the laying and operation: the load current, the length of the cable to be laid out, the spacing between the cables, and the power frequency. This research aims to reduce or eliminate the losses of the cable sheath. These two types of currents cause losses that may sometimes equal the losses of the conductor of the cable carrying the load current. Which reduces the capacity of the cable and reduces the heat dissipation of the cable into the soil and damages it. Electricians are at risk of electrocution due to the high voltages of the sheaths when there is no current in the sheaths. Therefore, these currents and voltages must be eliminated by making a new model that studies the effect of all these factors on them.

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## 1. INTRODUCTION

The danger of electric shock and fault currents is reduced with electric shock and fault currents reduced with electric shock, and fault currents reduced with insulating material for high voltage underground cables compared to the overhead transmission lines [1], [2]. Single-core cables have a high current capacity, so they are more likely to be used for high power transmission than three core cables [3], [4]. The cable insulation material is covered with metal tape or wires (sheath) to return fault and capacitive current, reduce the mechanical effects on the main conductor and prevent the electric field effect outside this sheath [5]. An induced voltage is generated at the metal sheath due to the passage of load current that magnetic product flux, which penetrates this sheath as explained in (one end bonding). A current flow between the ground and the sheath when it is grounded at (both ends); its value depends mainly on the sheath voltage and its impedance, causing so-called circulating losses [6]. Overheating the soil surrounding the cable due to conductor and circulating sheath currents may cause the soil surrounding the cable due to conductor and circulating sheath currents may cause the insulation's thermal breakdown [7]. The factors affecting circulating currents are discussed, and several methods of connecting cable sheaths are presented to reduce the risk of the sheath (voltages and losses) [8]–[13]. Therefore, the sheath current value must be reduced on the metallic sheath to prevent its negative effects, and the metallic sheath must be grounded to reduce the sheath current effect.

Single-point bonding, solid bonding, and cross bonding are used to ground metallic sheath of high voltage underground cable [14], [15]. Sheath voltages and currents can be found by modeling their formulation to determine the required precaution before installing these underground cables. However, these equations' difficulty because of multiple factors affecting their values made their simulation difficult [16].

The standard equation is utilized to determine sheath resistance, sheath losses with multiple cables arrangements, and conductor's resistivity [17]. Sheath and conductor losses with two ends bonding are determined theoretically in [13]. In thermal analysis, volumetric heat source, the volumetric heat source in thermal analysis, is found by implementing losses determination in sinewave currents of underground cables in [18]. Several factors like radiuses and distances between cables and phase current alterations are used to determine sheath voltage [19]–[21].

## 2. LITERATURE SURVEY

Boyde [10], studied how to reduce and eliminate the eddy current by connecting a current transformer at the load side, where the metallic cable is connected at the primary part of the transformer. Then, it should be grounded from this side and the source side (two-point bonding). Next, the secondary part of the current transformer is connected to a voltage transformer. This connection aims to make the voltage transformer convert a voltage equal to the induced sheath voltage and opposite to it at an angle of 180 degrees to avoid passing away of any circulating current in the metal cover. Ma *et al.* [12], used a compensating inductance coil, where one end is connected to the end of the sheath and the other end to the ground. As a result, an induced electromotive force is generated, opposite in the direction of the remaining voltage in the sheath. This generated voltage is due to the induction of the magnetic flux resulting from the load current. This coil is used in case of cross-bonding because the three parts of cable sheaths are not equal. From practical experience, all of these methods cause a high cost. In addition, the fault current in long-distance cables will lead to weakening all the joints that pass through on its way back. In this research, a new model was made to compare the cables layout methods. In addition, a comparison between the sheath bonding methods is covered in this paper by studying the effect of (load current, cable length, frequency, distances between the cables) on these methods. Hence the lowest values for the currents and voltages of the sheaths are obtained, and consequently the best performance.

## 3. THE INDUCED SHEATH VOLTAGE OF SINGLE-CORE UNDERGROUND CABLES

Arrangements, construction, and length of cables must be considered when determining, and the length of cables must be considered when determining the sheath, and the length of cables must be considered when determining sheath-induced voltage [4], [22], [23]. Its value can be measured at the free point with respect to earth with earthing the other point, as explained in Figure 1. Each sheath per phase in the trefoil arrangement carries the voltage in (1).

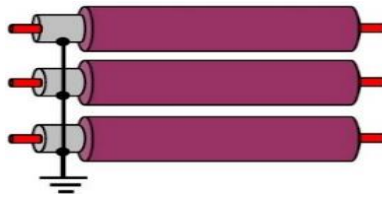


Figure 1. One-point sheath bonding

$$I_{cs1=0}, U_{s1} = U_{s2} = U_{s3} j\omega M I_1 \quad (1)$$

$U_{s1,2,3}$ : induced voltages in sheaths V/m

The equal spacing between the phases of power cables causes similar sheath induced voltages. Where  $M$  is the mutual inductance and depends on the spacing between axes of any adjacent cables ( $S$ ) and the mean radius of the circle formed by the sheath conductor as,

$$M_{1,2} = M_{2,3} = M_{1,3} = M = 2 * 10^{-7} \ln \left( \frac{S}{r_{sh}} \right) \text{ Hm}^{-1} \quad (2)$$

either the spacing in the flat formation arrangement is different because of the outer cables as,

$$\left. \begin{aligned} U_{s2} &= -\frac{I_3}{2} [\sqrt{3}(X + X_m) + j(X - X_m)] \\ U_{s3} &= j\omega M I_3 \\ U_{s1} &= -\frac{I_3}{2} [-\sqrt{3}(X + X_m) + j(X - X_m)] \end{aligned} \right\} \quad (3)$$

$I_{1,2,3}$ : load three phase currents

$$M_m = 2 * 10^{-7} * \ln 2 = 1.389 * 10^{-7} \frac{H}{m}$$

$$X = \omega * M, \text{The reactance per unit length of sheath } \frac{\Omega}{m}$$

$X_m = \omega * M_m$ , Mutual reactance per unit length of cable between the sheath of an outer cable and the conductors of the other two, when cables are in flat formation  $\frac{\Omega}{m}$ . It is clear from (3), the middle cable has equal spacing from the outer two cables, and its sheath voltage is similar to those of trefoil formation arrangement.

#### 4. SHEATH LOSSES OF SINGLE-CORE UNDERGROUND CABLES

Sheath losses are current-dependent and can be divided into two categories according to the type of bonding [4], [24], [25]. Sheath circulating losses appear due to the sheath bonding from both ends as a result of passing a current between the sheath and the ground. Eddy losses occur regardless of bonding type (one point, two points, or cross bonding).

##### 4.1. Sheath circulating losses

Two points bonding causes the flowing of sheath circulating currents, leading to circulating losses, as explained in Figure 2. The voltages above and the impedance represented by the sheath resistance and sheath reactance define the circulating current in trefoil and flat arrangement. The sheath impedance of three-phase cables in the trefoil arrangement is the same because of the equal spacing. Based on this, circulating sheath current per phase of the three cables can be written as (4).

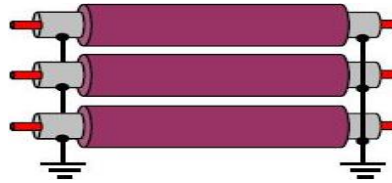


Figure 2. Two-point sheath bonding

$$I_{cs1} = I_{cs2} = I_{cs3} = I_1 \frac{-j\omega M}{R_s + j\omega M} \quad (4)$$

From (4), the sheath circulating loss and factor are explained:

$$W_{cs} = |I_{cs}|^2 R_s = |I|^2 R_s \left( \frac{\omega^2 M^2}{R_s^2 + \omega^2 M^2} \right) Wm^{-1} \quad (5)$$

$$\delta_{cs} = \frac{R_s}{R} \left( \frac{\omega^2 M^2}{R_s^2 + \omega^2 M^2} \right) \quad (6)$$

Where the factor in (6) is the ratio of sheath circulating loss to the conductor load loss in  $Wm^{-1}$ . However, this is not true in the flat arrangement at two-point sheath bonding where the sheath circulating equations are more complicated than trefoil one because the different spacing between the cables results in unequal sheath voltages, impedances, and currents. These currents of this arrangement can be calculated from (7)-(9).

$$I_{cs1} = \frac{I_2}{2} \left[ \left( \frac{Q^2}{R_s^2 + Q^2} + \frac{\sqrt{3}R_s P}{R_s^2 + P^2} \right) + j \left( \frac{R_s Q}{R_s^2 + Q^2} - \frac{\sqrt{3}P^2}{R_s^2 + P^2} \right) \right] \quad (7)$$

$$I_{cs2} = -I_2 \left( \frac{Q^2}{R_s^2 + Q^2} + j \frac{R_s Q}{R_s^2 + Q^2} \right) \quad (8)$$

$$I_{cs2} = -I_2 \left( \frac{Q^2}{R_s^2 + Q^2} + j \frac{R_s Q}{R_s^2 + Q^2} \right) \quad (9)$$

The sheath losses per meter for each phase and the loss factor are written in (10)-(12):

$$W_{cs1} = I_{cs1}^2 R_s \quad W_{cs2} = I_{cs2}^2 R_s \quad W_{cs3} = I_{cs3}^2 R_s \quad (10)$$

$$\delta_{cs3} = \frac{I_{cs2}^2 R_s}{I^2 R} = \frac{R_s}{R} \left( \frac{Q^2}{R_s^2 + Q^2} \right) \quad (11)$$

$$\delta_{cs1} = \frac{I_{cs3}^2 R_s}{I^2 R} = \frac{R_s}{R} \left[ \frac{Q^2}{4(R_s^2 + Q^2)} + \frac{3P^2}{4(R_s^2 + P^2)} + \frac{2QR_s P X_m}{\sqrt{3}(R_s^2 + Q^2)(R_s^2 + P^2)} \right] \quad (12)$$

$I_{cs1,2,3}$  sheath circulating currents

$$P = X + X_m$$

$$Q = X - \frac{X_m}{3}$$

$R_s$ : sheath resistance at maximum operating temperature  $\frac{\Omega}{m}$

$R$ : main conductor resistance  $\frac{\Omega}{m}$

Three-phase arrangement with sheaths cross-bonded for long-run length and spacing of cables can be allowed by eliminating exaggerated sheath voltage and circulating current using cross-bonding methods. Current-carrying capacity is improved after increasing cables spacing with this method because of each cable's thermal independence. The induced voltage is canceled by dividing the cable run into three parts (sections) and cross-connecting the sheaths, as explained in the Figure 3.

In the first part, the sheath end of the first cable is cut and connected to the sheath beginning of the second cable in the middle part. It was connecting the second cable's sheath end-point with the third cable's beginning sheath point in the last section to make the directional summation of induced voltages in all parts equal to zero without flowing any circulating current except the eddy currents. This method is most likely to be employed in very high voltage cables because its expansiveness [4], [23]–[25].

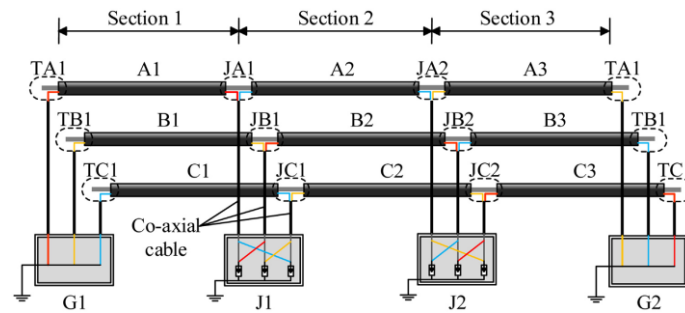


Figure 3. Sheath cross bonding

#### 4.2. Sheath eddy losses

Whether single or three cores, different bonding methods and cable types will not prevent eddy current losses from occurring. In solid bonding (two ends) for sheaths of single-core cable, the circulating current losses are enormous compared to these losses, and therefore, they can be neglected if the cable conductor layers have small segments. The flowing eddy current is due to the different voltages on the sides of the sheath. The density of the non-uniform current in the cable conductors makes (ep) on the outer surface of the sheath lower than on the inner one because of their convergence from each other. This indicates that the divergent cables eliminate this type of currents [4], [22], [23]. The sheath eddy current and loss factor will be calculated by (13) and (14).

$$I_{SE} = \sqrt{\frac{3I^2 \omega^2}{R_s^2} \left( \frac{r_{sh}}{s} \right)^2} * 10^{-14} \quad (13)$$

$$\delta_{SE} = \frac{3\omega^2}{R_s R} \left( \frac{r_{sh}}{S} \right)^2 * 10^{-14} \quad (14)$$

Where:

$\delta_{SE}$  : Eddy loss factor of the sheath

$I_{SE}$ : Sheath eddy-current in A

Nevertheless, in the flat arrangement, their values calculated by (15) to (16).

$$\delta_{SE1} = \delta_{SE3} = \frac{3\omega^2}{2R_s R} \left( \frac{r_{sh}}{S} \right)^2 * 10^{-14} \quad (15)$$

$$I_{SE1} = I_{SE3} = \sqrt{\frac{3I^2\omega^2}{2R_s^2} \left( \frac{r_{sh}}{S} \right)^2 * 10^{-14}} \quad (16)$$

$$\delta_{SE2} = \frac{6\omega^2}{R_s R} \left( \frac{r_{sh}}{S} \right)^2 * 10^{-14} \quad (17)$$

$$I_{SE2} = \sqrt{\frac{6I^2\omega^2}{R_s^2} \left( \frac{r_{sh}}{S} \right)^2 * 10^{-14}} \quad (18)$$

Where:

$\delta_{SE1}$  ,  $\delta_{SE3}$ , Eddy loss factor of the sheath in two outer cables

$\delta_{SE2}$ , Eddy loss factor of the sheath in middle cable

$I_{SE1}$ ,  $I_{SE3}$ : Sheath eddy-current in two outer cables in A

$I_{SE2}$ : Sheath eddy-current in middle cable in A

In the sheath cross-banded case, the eddy loss factor and currents calculated by (19) and (20).

$$\delta_{SE} = \frac{R_s}{R} \left[ g_s \gamma_c (1 + \Delta 1 + \Delta 2) + \left( \frac{(\beta_1 t_s)^4}{12 * 10^{12}} \right) \right] \quad (19)$$

$$I_{SE} = I \left[ g_s \gamma_c (1 + \Delta 1 + \Delta 2) + \left( \frac{(\beta_1 t_s)^4}{12 * 10^{12}} \right) \right]^{\frac{1}{2}} \quad (20)$$

$$g_s = 1 + \left( \frac{t_s}{D_s} \right)^{1.74} (\beta_1 D_s 10^{-3} - 1.6) \quad (21)$$

$$\beta_1 = \sqrt{\frac{4\pi\omega}{10^7 \rho_s}} \quad (22)$$

$\rho_s$ : The electrical resistivity of sheath material at operating temperature ( $\Omega.m$ )

$D_s$ : The external diameter of the cable sheath (mm)

$t_s$  : The thickness of sheath (mm)

$\Delta 1$  and  $\Delta 2$  are factors whose values depend on the types of cable layouts formation.

$g_s$  and  $\beta_1$  are factors whose values depend on the cable parameters.

For ( $m \leq 0.1$ ,  $\Delta 1$  and  $\Delta 2$  can be neglected)

Where: ( $m$ ) is a factor that depends on power frequency and metallic sheath resistance.

These values can be calculated from [4], [23], [24].

## 5. SIMULATION AND RESULTS

The (1) to (23) have been simulated by the method of mathematics simulation. All equations include dependent and non-dependent variables. The independent variables were utilized as variable inputs to show the effect on all equation's outputs. Figure 4 illustrates all of these inputs with their sub-inputs values. The Figures 5-19 represent simulation parts of the sheath voltages, currents, and loss factors in one modeling for two layout formations (trefoil and flat).

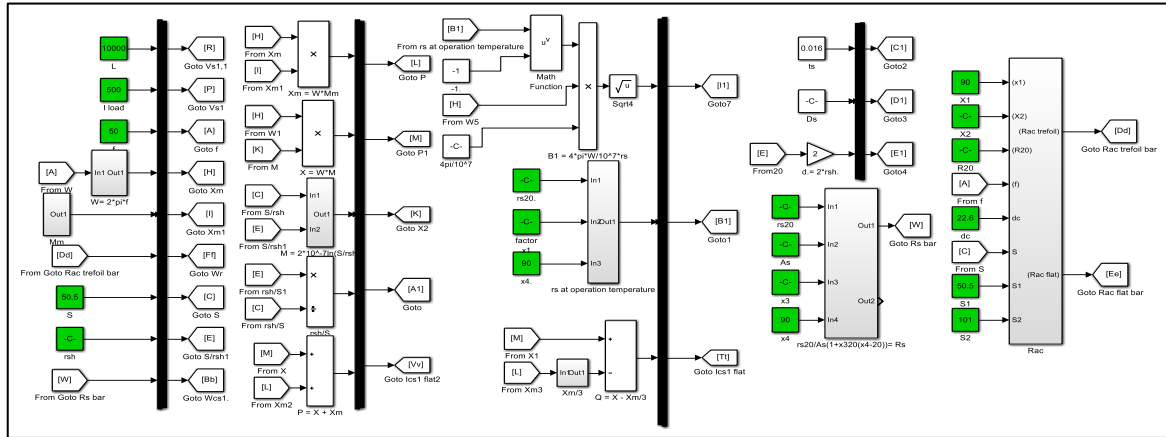


Figure 4. The input and their branches

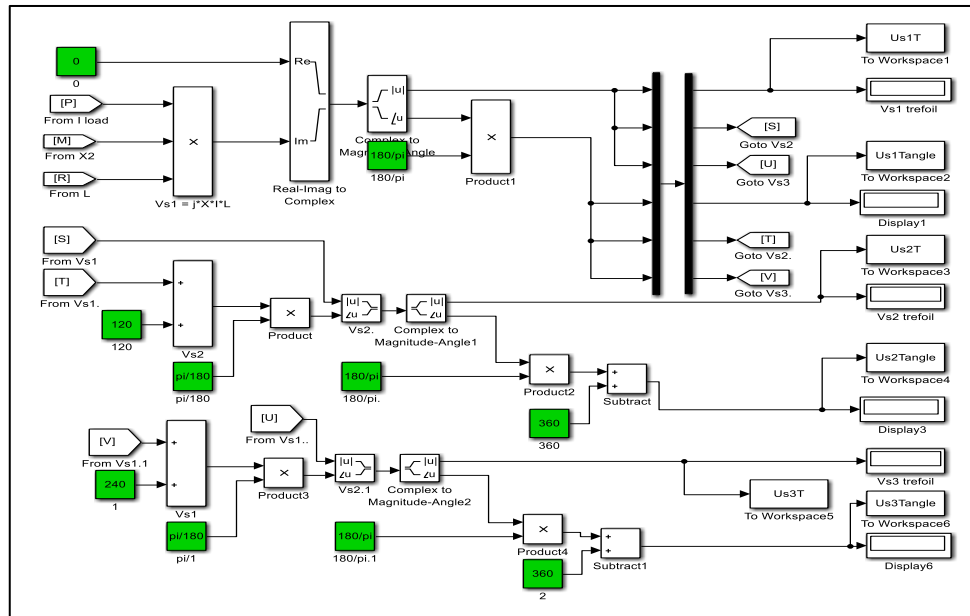
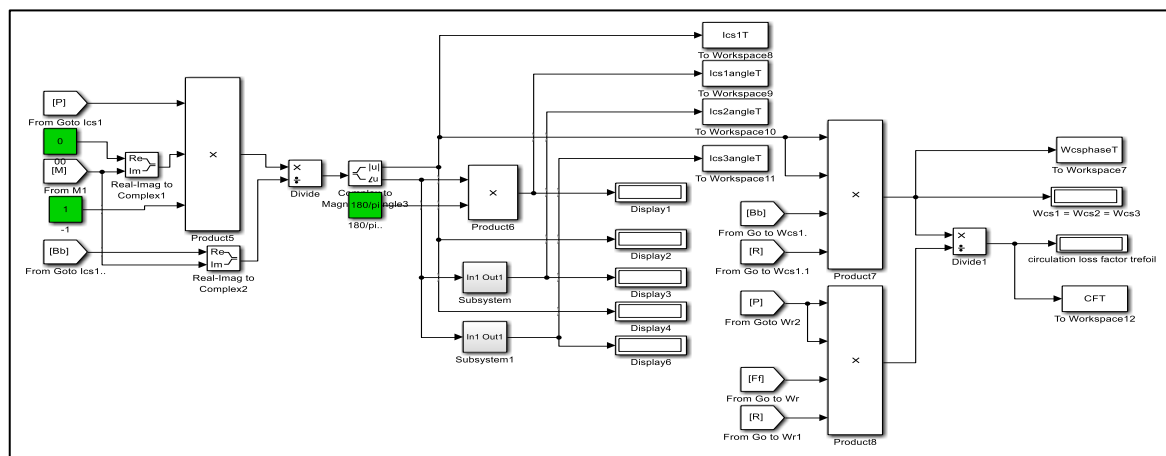
Figure 5. Sheath voltage  $U_{s1}$ ,  $U_{s2}$ ,  $U_{s3}$  for trefoil arrangement single point earthing

Figure 6. Circulation (currents, losses and loss factor) simulation circuit equations of trefoil arrangement of two-point earthing

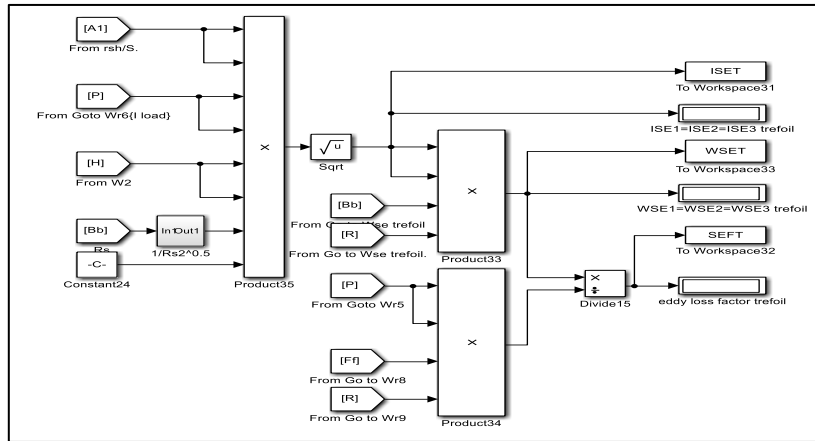


Figure 7. Eddy (currents, losses, and loss factor) simulation circuit equations of trefoil arrangement

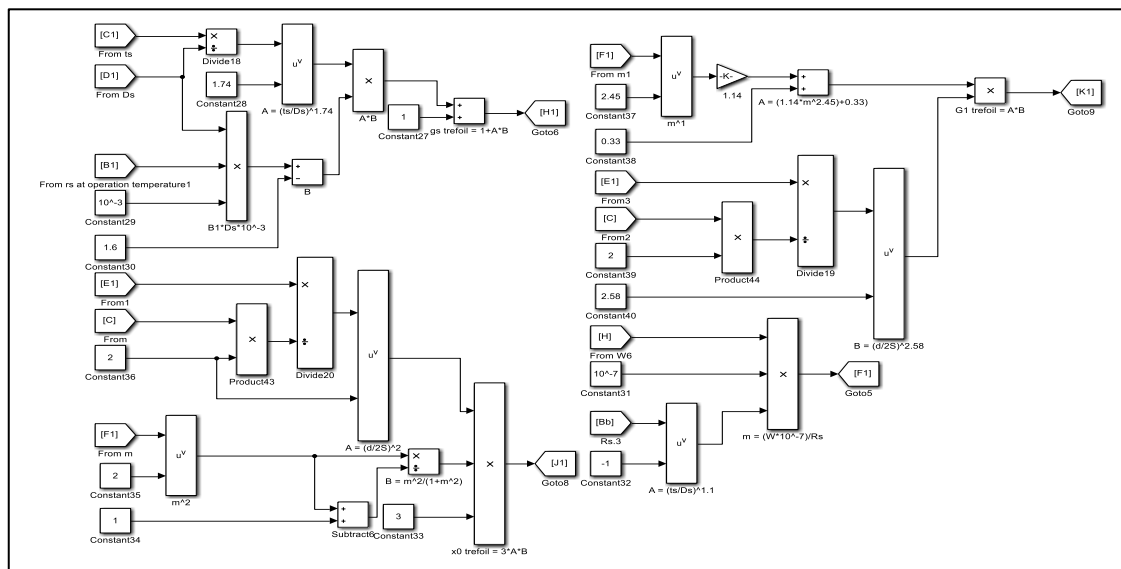


Figure 8. ( $x_0$ ,  $m$ ,  $gs$ ,  $G_1$ ) parameters for trefoil arrangement

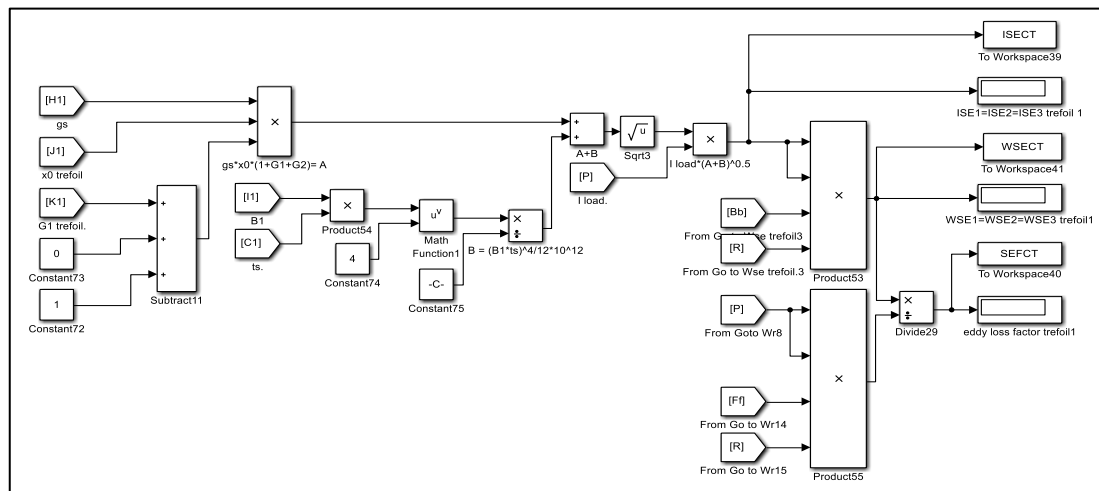


Figure 9. Eddy (currents, losses, and loss factor) simulation circuit equations of trefoil cross bonding arrangement earthing

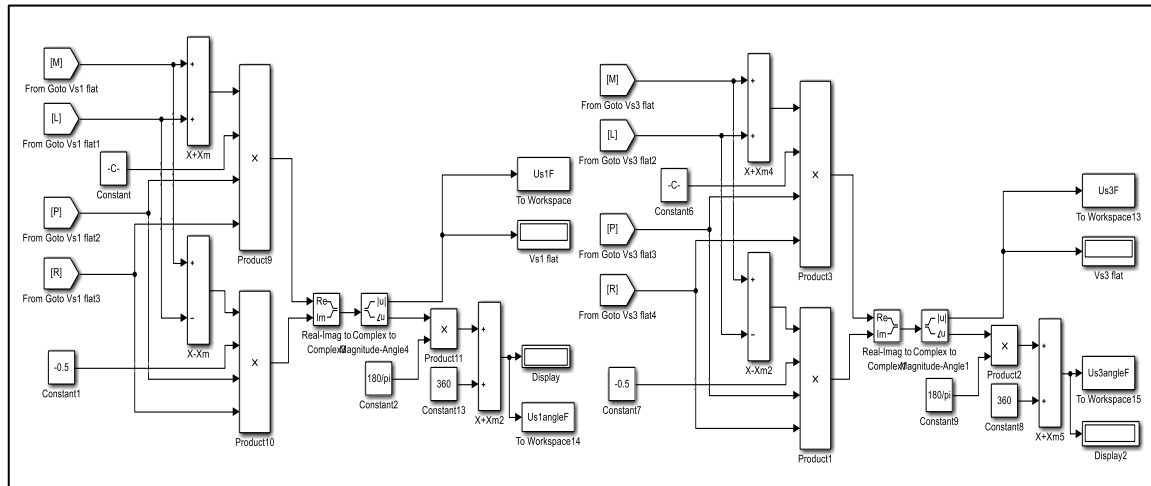
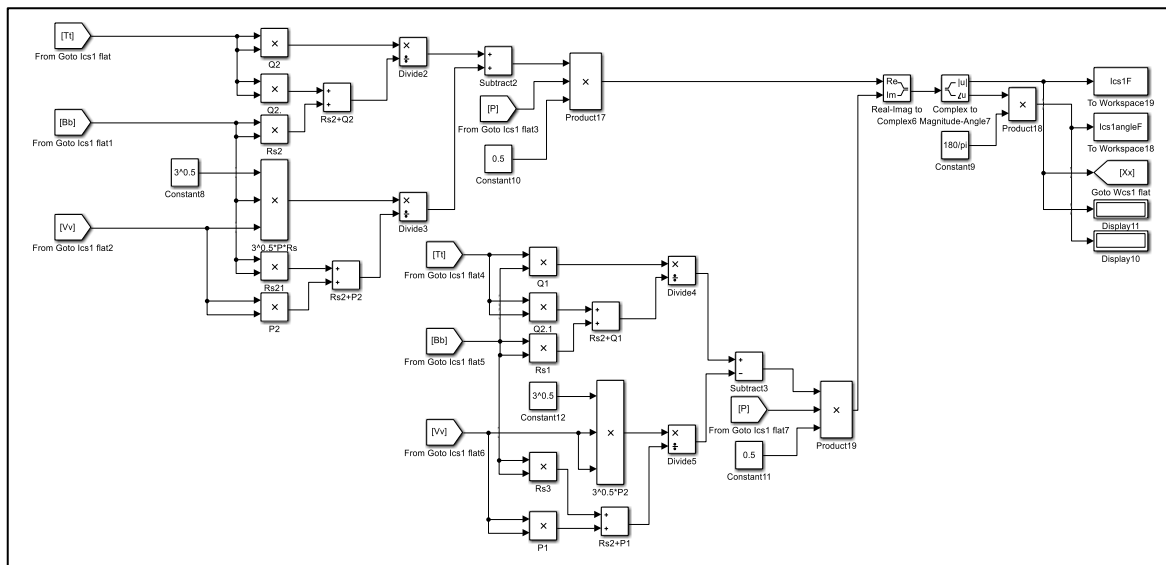
Figure 10. Sheath voltage  $Us_1$ ,  $Us_3$  for flat arrangement single point earthing

Figure 11. Circulation currents simulation circuit equations of the flat arrangement of two points earthing

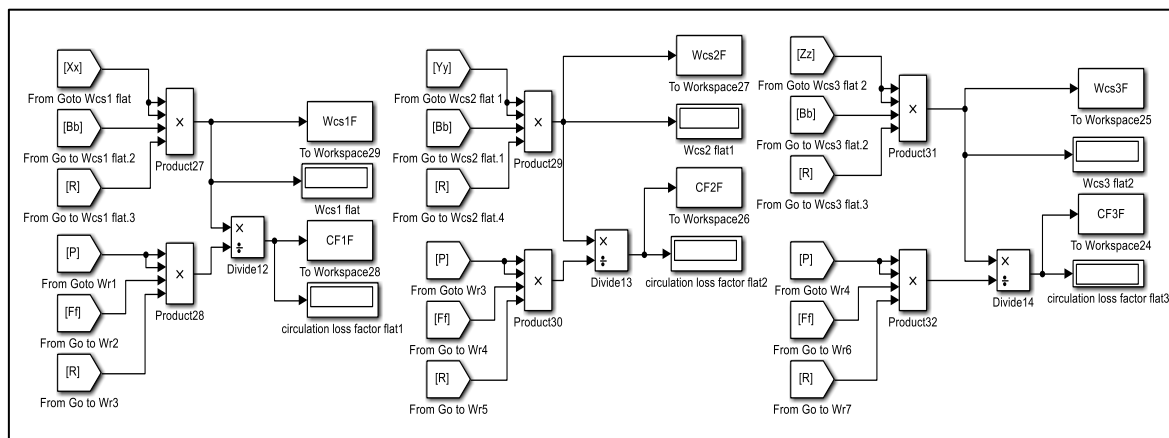


Figure 12. Circulation (losses and loss factor) simulation circuit equations of the flat arrangement of two-point earthing



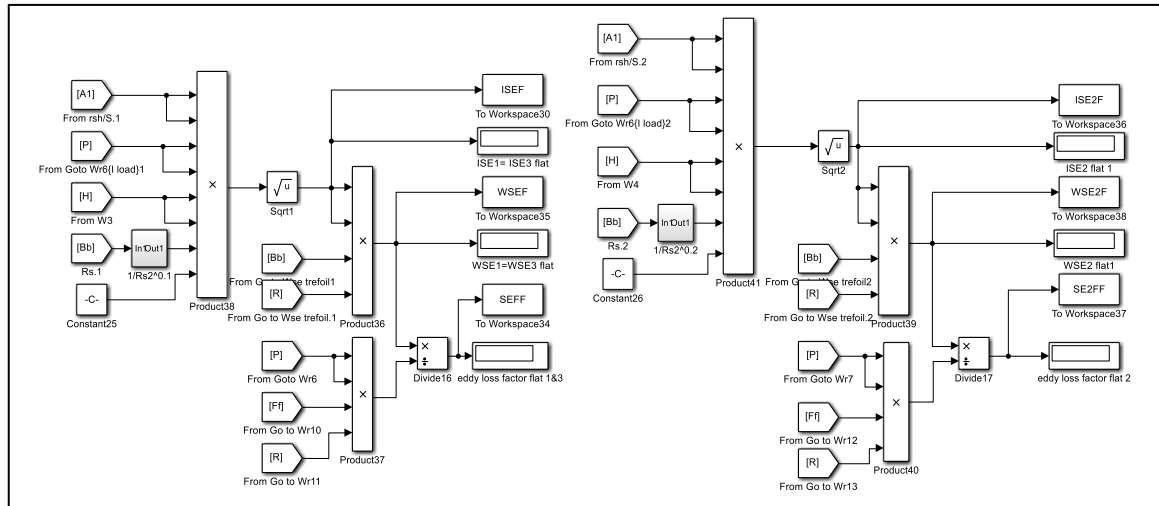


Figure 13. Eddy (currents, losses and loss factor) simulation circuit equations of flat arrangement

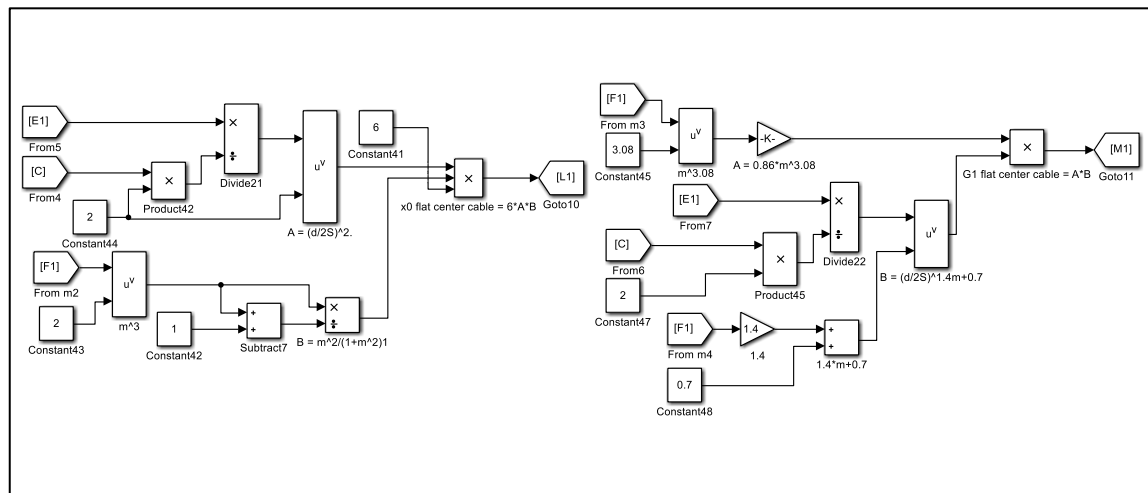


Figure 14. (x0, G1) parameters for center cable flat arrangement

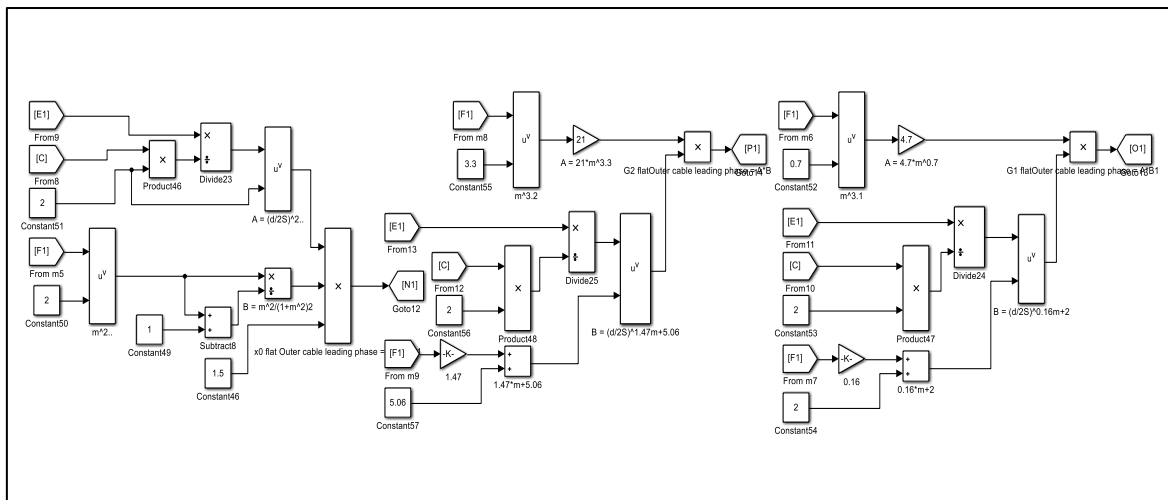


Figure 15. (x0, G1, G2) parameters for leading cable flat arrangement

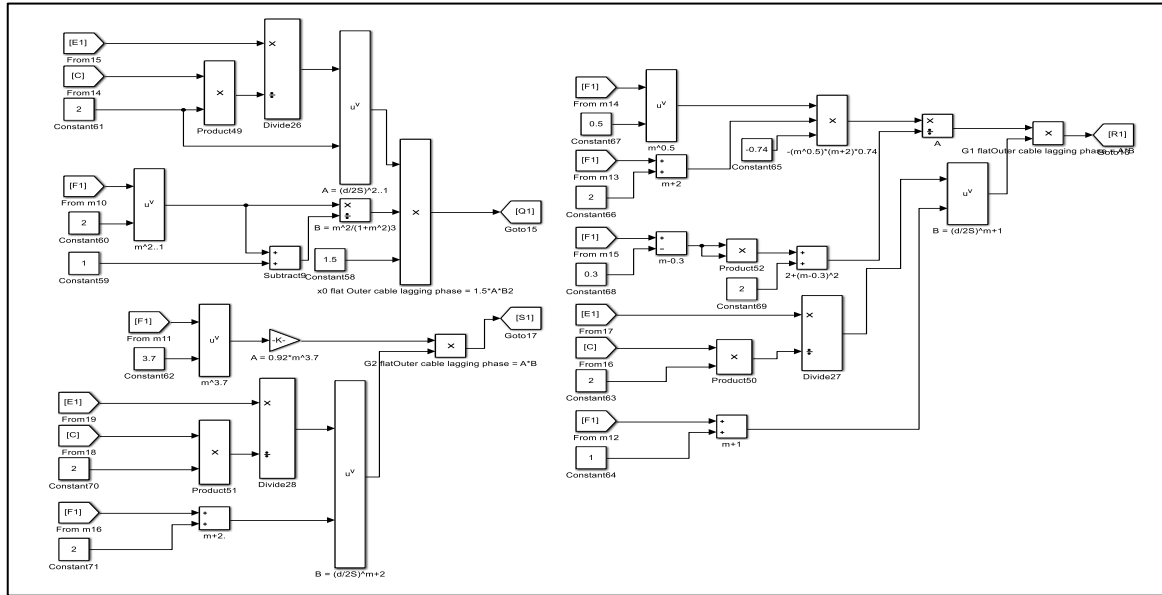
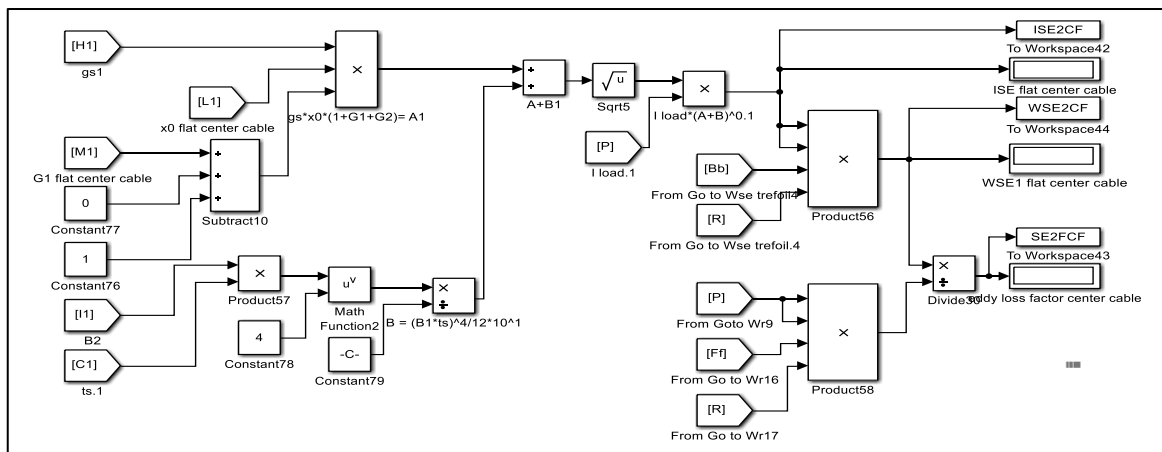
Figure 16. ( $x_0$ ,  $G_1$ ,  $G_2$ ) parameters for lagging cable flat arrangement

Figure 17. Eddy (currents, losses, and loss factor) simulation circuit equations for the center cable of flat cross bonding arrangement

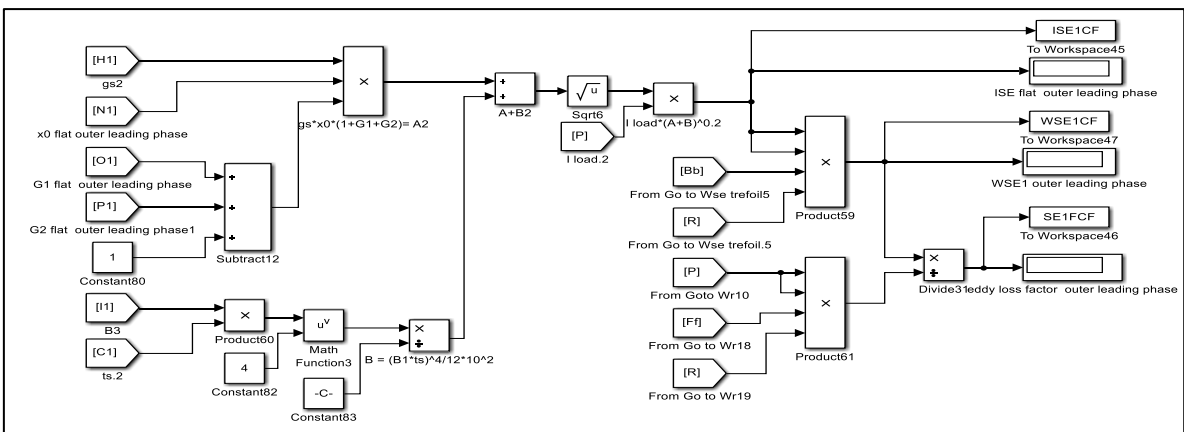


Figure 18. Eddy (currents, losses, and loss factor) simulation circuit equations for outer cable leading phase of flat cross bonding arrangement

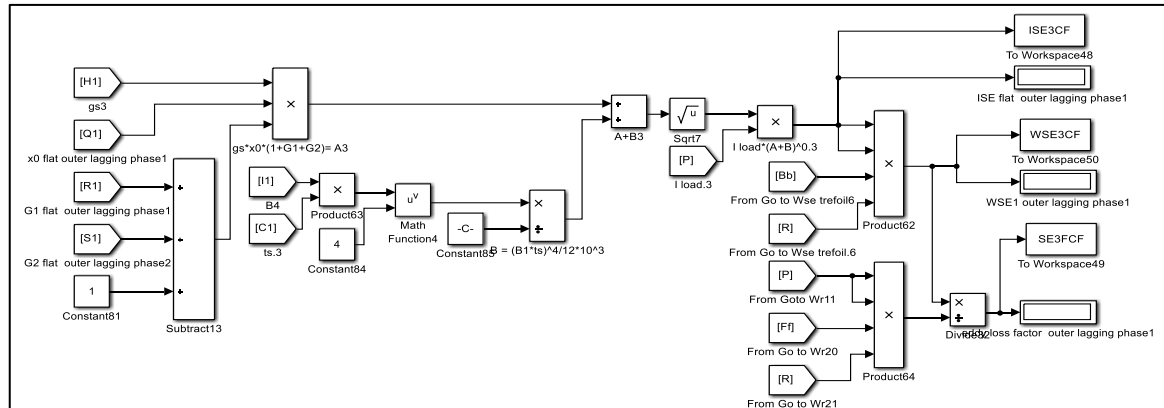


Figure 19. Eddy (currents, losses and loss factor) simulation circuit equations for outer cable lagging phase of flat cross bonding arrangement

Parameters of input values for  $1 \times 400 \text{ mm}^2$ , 19/33 kv underground single core cable in Table 1 are taken from [26]. When the value of the load current changes within the range (200-500), the cable sheaths' voltages will change at the trefoil and flat arrangements as in Figure 20 in the case of the sheaths being grounded from one end only. The sheaths of the three-phase for the trefoil, and the mid-phase one in the flat arrangement will increase within the range (108.56-304) V, while the limits for those of the outer phases of the flat arrangement are (169.8-475.4) V.

The circulating currents results when the sheaths are grounded at both ends are shown in Figure 21. The circulating currents in the trefoil and the center one of the flat arrangements have equal values within the range (17.22-48) A while the currents of the external cables increased within the range (26.8-75) A and (27.25-78-26) A. The results show the difference in the rate of increase of sheath currents at low and high load currents concerning cable sheaths for flat and trefoil arrangement. This is because the difference in distances between the power cables in a flat one causes a difference (increase) in the reactance value on the outer cable sheaths, thus an apparent increase in the sheath voltage circulating currents.

Table 1. Parameters of underground cable  $1 \times 400 \text{ mm}^2$  19/33 kv

Cable parameters	Parameters values
$dc$	22.6 mm
$A_s$	35 $\text{mm}^2$
$r_{sh}$	21.287 mm
$S$	50.5 mm
$R_{dc20}$ for conductor	0.047 $\Omega/\text{k}$
$\rho_{s20}$	$1.7241 \times 10^{-8} \Omega \cdot \text{m}$
$\alpha_{c \text{ or } s20}$	$3.93 \times 10^{-3}$

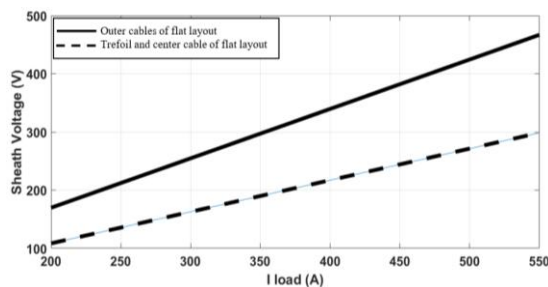


Figure 20. Sheath voltages with load current

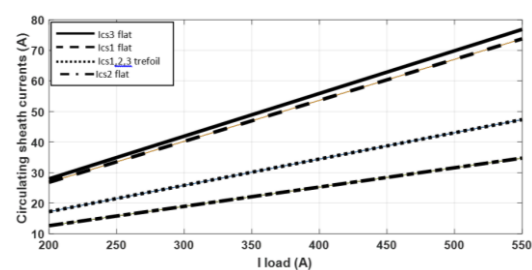


Figure 21. Eddy currents with load current

The increase in the sheath circulating currents increases the sheath circulating losses and factors, as shown in Figure 22 and within the range in Table 2. Figures 23 to 26 in addition to the Table 3 of information

for currents and their losses indicate that eddy currents decrease as the resultant magnetic flux which induces the sheath voltage is more uniform on that sheath. This talk crystallizes its result in the external cables of flat layout formation compared to those of the middle cable and the three cables of trefoil arrangement where they carry the lowest sheath eddy currents and then cause the smallest losses.

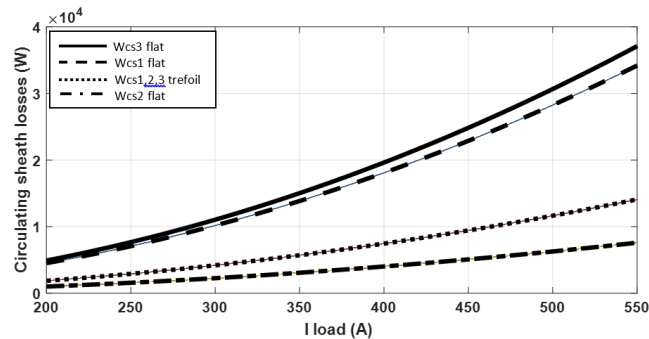


Figure 22. Circulating losses with load current

Table 2. Sheath circulating currents, their losses and loss factors in trefoil and flat cables arrangements with two-point bindings when the load current changes (200-500)

Sheath circulating currents, their losses and loss	Values
Load currents	(200-550) A
Circulating currents for trefoil and center cable in flat layout formation	(17.22-48) A
Circulating current for the outer first cable in flat layout formation	(26.8-75) A
Circulating currents for center cable in flat layout formation	(12.64-34.75) A
Circulating current for the outer third cable in flat layout formation	(27.25-78-26) A
Circulating losses for trefoil layout formation	(1.86-14.6) KW
Circulating losses for the outer first cable in flat layout formation	(4.521-35.44) KW
Circulating losses for center cable in flat layout formation	(1-7.6) KW
Circulating losses for the outer third cable in flat layout formation	(4.91-38.47) KW
Circulating factor for trefoil and layout formation	0.081
Circulating factor for the outer first cable in flat layout formation	0.2
Circulating factor center cable in flat layout formation	0.044
Circulating factor for the outer third cable in flat layout formation	0.214

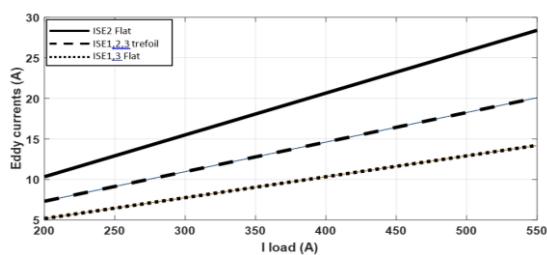


Figure 23. Eddy currents with load current

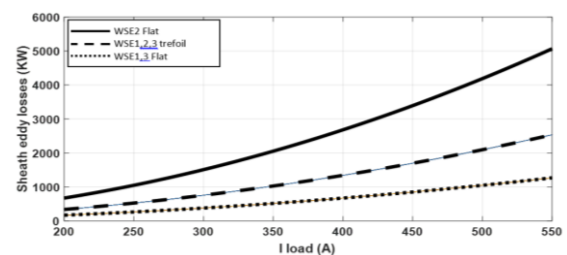


Figure 24. Eddy losses

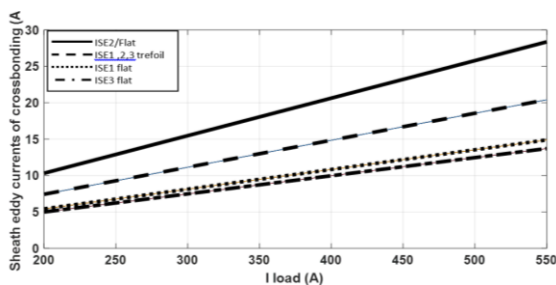


Figure 25. Eddy currents cross-bonding

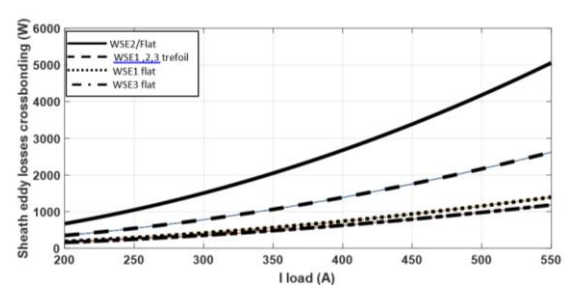


Figure 26. Eddy losses cross-bonding

Table 3. Sheath eddy currents, their losses and loss factors in trefoil and flat cables arrangements with single, two points

Sheath eddy currents, their losses and loss factors	values
I load	(200-550) A
Trefoil Sheath eddy currents	(7.3-20.08) A
Flat Sheath eddy current for center cable	(10.33-28.4) A
Flat Sheath eddy current for outer cables	(5.164-14.2) A
Trefoil Sheath eddy losses	(335.023-2534) W
Flat Sheath eddy losses for center cable	(670.046-5067) W
Flat Sheath eddy losses for outer cables	(167.51-1270) W
Trefoil Sheath eddy factor	0.015
Flat Sheath eddy factor for center cable	0.03
Flat Sheath eddy factor for outer cables	0.007
Trefoil Sheath eddy currents (cross-bonding)	(7.42-20.4) A
Flat Sheath eddy current for center cable (cross-bonding)	(10.32-28.37) A
Flat Sheath eddy current for first cable (cross-bonding)	(5.41-15) A
Flat Sheath eddy current for third cable (cross-bonding)	(5-13.7) A
Trefoil Sheath eddy losses (cross-bonding)	(346.09-2617.3) W
Flat Sheath eddy losses for center cable (cross-bonding)	(668.4-5055) W
Flat Sheath eddy losses for first cable (cross-bonding)	(184.12-1392) W
Flat Sheath eddy losses for third cable (cross-bonding)	(156-1180) W
Trefoil Sheath eddy loss factor (cross-bonding)	0.0151
Flat Sheath eddy loss factor for center cable (cross-bonding)	0.029
Flat Sheath eddy loss factor for first cable (cross-bonding)	0.008
Flat Sheath eddy loss factor for third cable (cross-bonding)	0.0068

The case of changing the length of cables with a constant load current at 400 A. The effect of changing the cable's length on the values of both sheath voltages, circulating and eddy losses are evident in Figures 27 (a)-(d), as its increasing increases the mentioned outputs while the currents causing these losses remain unchanged. The external cables' position in the flat layout formation results in the highest levels of circulating and the lowest eddy losses.

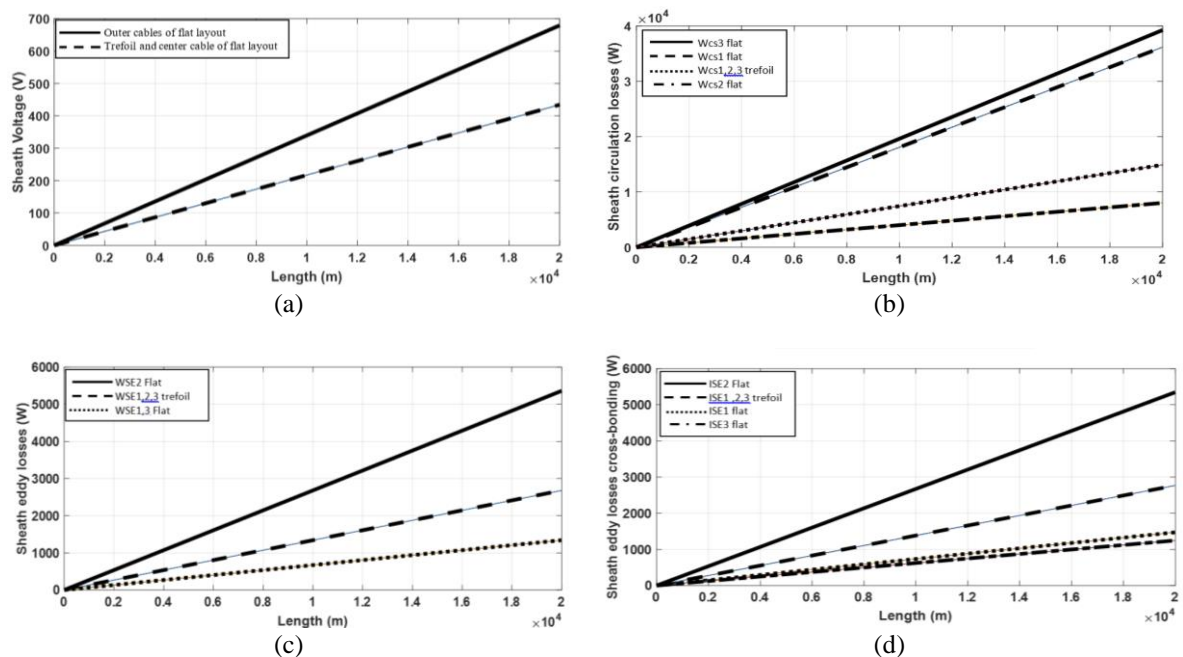


Figure 27. Voltages and losses with cable's length: (a) sheath voltages with length, (b) sheath circulation losses with length, (c) sheath eddy losses with length and (d) eddy losses cross-bonding

Cables spacing effect with constant load current at 400 A and length = 10000 m. The cables' spacing is considered an independent variable in a logarithmic function, causing an increasing of sheath voltages, circulating currents, losses, and their factors with decreasing the eddy currents, their losses and factors

exponentially as explained in Figures 28 (a)-(h). Frequency effect at (50-60) range with constant load current at 400 A,  $S=50.5$  mm and length = 10000 m. All outputs will increase linearly with this range as explained in Figures 29 (a)-(c), their ranges and those of the load current and length effect are smaller than the cables spacing effect.

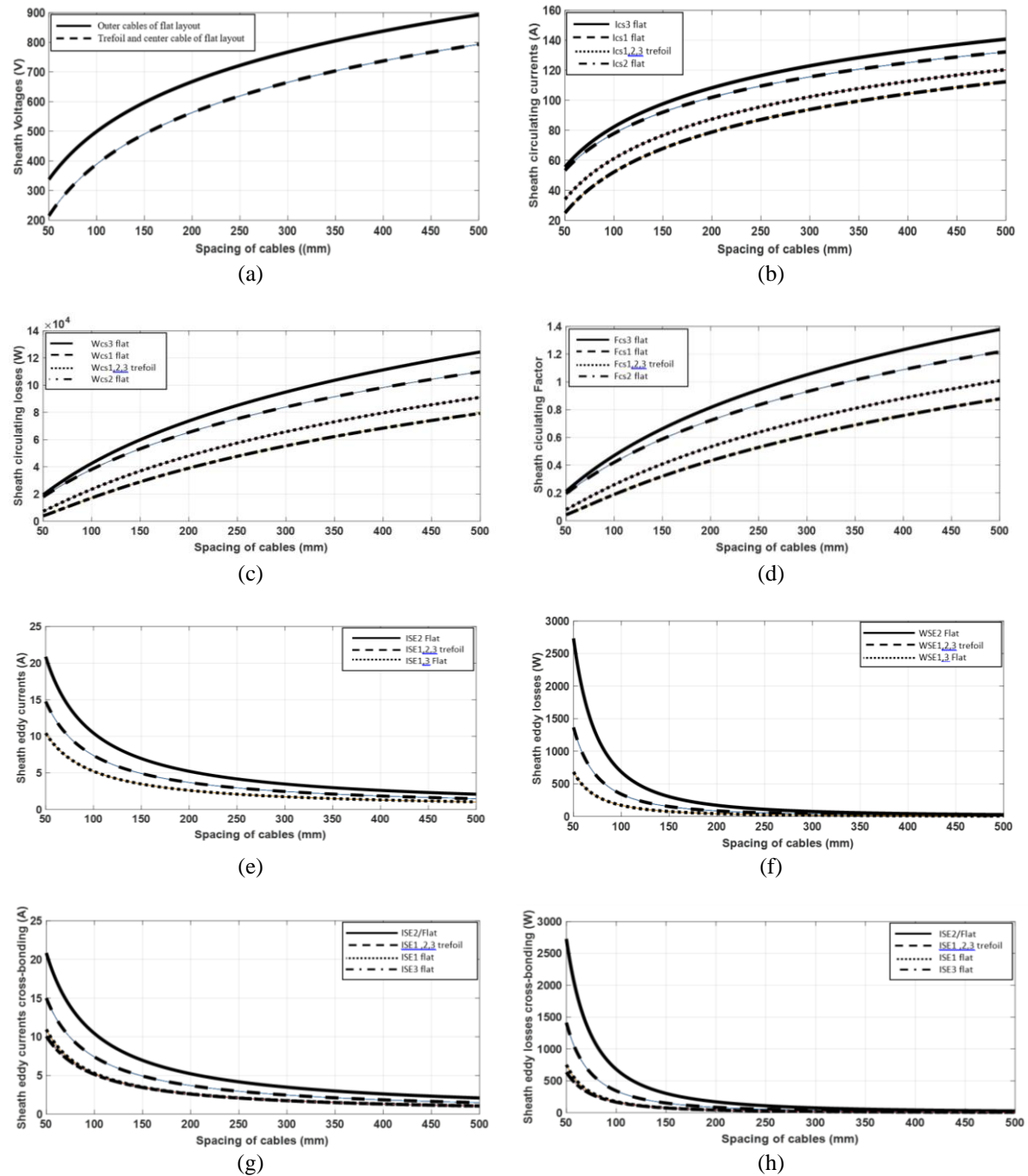


Figure 28. Voltages, currents, losses and factors with cable's spacing: (a) sheath voltages with spacing, (b) circulating currents with spacing, (c) circulating losses with spacing, (d) circulating loss factor with spacing, (e) eddy currents with spacing, (f) eddy losses with spacing, (g) eddy currents cross-bonding with spacing and (h) eddy losses cross-bonding with spacing

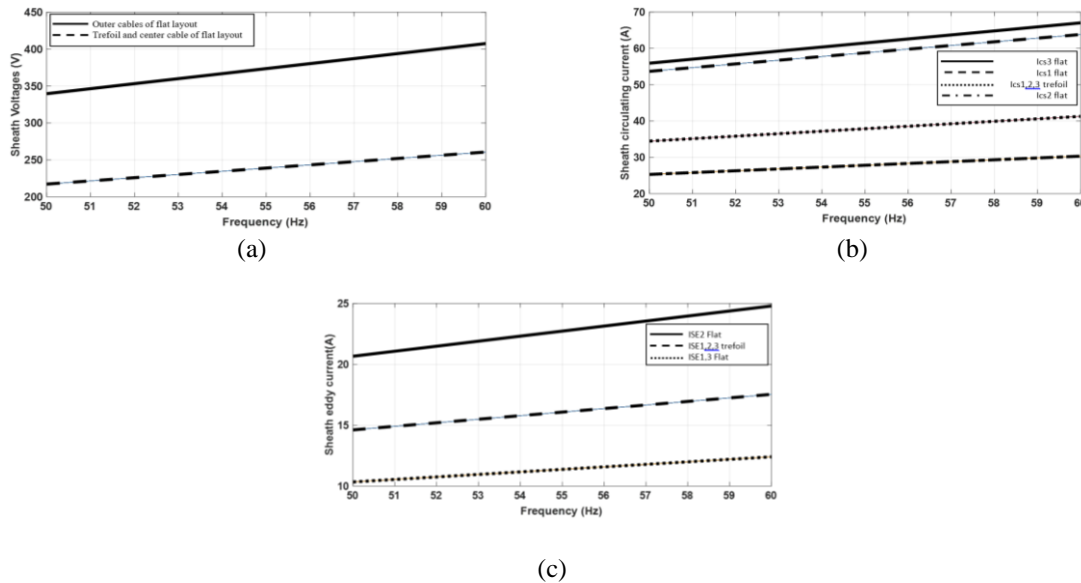


Figure 29. Voltages and currents with frequency: (a) sheath voltages with frequency (b) sheath circulating currents with frequency, and (c) sheath eddy currents with frequency

## 6. CONCLUSION

In (1) to (22) were simulated using the MATLAB program in this paper. The elements in the Math Operation List were used to solve these equations. These equations' outputs are mainly related to the cables' trefoil and flat arrangements when their sheaths are connected to the ground from one point, two points, or cross-connected. Keep attention to load current, cable length, spacing, and power frequency values before proceeding with any laying method. When the cable's sheath is connected from two points, the load on the cable should be reduced to less than the permissible limit when connected from one point because its capacity will be minor. Otherwise, the cable will be broken down. The eddy current losses can be ignored because it is minimal compared to the circulating current losses. It is not recommended to set the phase far apart from each other because this leads to an increase in the sheath voltage and the circulating currents exponentially. The sheath voltage can go up to 900 volts if one end is connected and the currents can arrive to 160 amps if two ends are connected. This is very risky on the cable condition and the safety of the electricians at maintenance. It is better to work at a frequency of 50 Hz. Finally, the best way to reduce the sheath voltages without any circulating current will be determined, in addition, a second path to return the fault current without weakening the cable connection points caused by all of the above methods. This process can be done by cutting the sheaths of the long cables at every joint. First, all the points at the beginning of every section are connected to the external insulated conductor. Then the cable is grounded from the two ends to guarantee passing the fault current through the external cable without causing damage to the joints. The total voltage of the sheath divided by the number of sections equals the sheath voltage of each section. Thus, if any sheath fault happens, the circulating current will flow in the defective section.

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