Influence of Reduction Factors on High Voltage Cables on the Transfer of Potentials in the Network

Nikolche Acevski[1], Angela Micevska[2], and Ana Manivilovska[3]

Abstract **- The purpose of this paper is to calculate the reduction factors of 3 single-core HV cables, that is, to see the differences in the voltage at two HV 110 kV substations, substation Central and transferred to substation South New, when applying HV cables with various cross-sections placed in triangle and plane configurations.**

Keywords **- Reduction factor, HV cables, Plane, Triangle, Transfer of potential.**

I. INTRODUCTION

The reduction factor of the HV cable is defined as the ratio between the residual current ($\underline{I}_{KV}$ - $\underline{J}_e$), which continues to the end of the cable, and the error current $\underline{I}_{KV}$, (10), (21). It shows us how much of the fault current will be injected into the grounding conductor at the end of the cable at the grounded connection at its end.

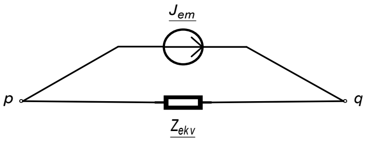

Fig. 1. Single-phase equivalent of 3 single-core cables

When the three single-core cables are laid in a triangular layout, as in Fig. 2, the followingapplies:

$$\underline{Z} = \begin{bmatrix} \underline{Z}_s & \underline{Z}_m & \underline{Z}_m \\ \underline{Z}_m & \underline{Z}_s & \underline{Z}_m \\ \underline{Z}_m & \underline{Z}_m & \underline{Z}_s \end{bmatrix} \quad (1)$$

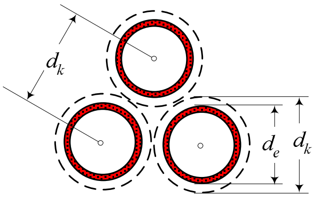

Fig. 2. Triangle configuration

The self and mutual impedances $\underline{Z}_s$ and $\underline{Z}_m$ on the three cores of the cables are calculated with Carson equations, [5], for ρ=300 Ωm. The cables are placed in a PVC pipe, d=0.16 m.

$$D_{ek} = 658\sqrt{\frac{\rho}{f}} = 658\sqrt{\frac{300}{50}} = 1611.76m, \quad (2)$$

$$\underline{Z}_s = (0.05 + r_e + j \cdot 0.1445 \cdot \log\frac{D_{ek}}{d_e/2}) \cdot l, \quad (3)$$

$$\underline{Z}_m = (0.05 + j \cdot 0.1445 \cdot \log\frac{D_{ek}}{D}) \cdot l. \quad (4)$$

So each cable with an insulated sheath observed along with its return path through the ground is represented by an I-replacement circuit. The mutual impedances between the phase conductor of phase f=A, B, C and the screens of the three wires of the cable are calculated according to (5). For phase A, (6).

$$\underline{M}_{ij} = 0.05 \cdot l + j \cdot 0.1445 \cdot \log\frac{D_{ek}}{d_e/2} \cdot l, \quad (5)$$

$$\underline{M}_{1A} = 0.05 \cdot l + j \cdot 0.1445 \cdot \log\frac{D_{ek}}{d_e/2} \cdot l \equiv \underline{M}_s, \quad (6)$$

$$\underline{M}_{2A} = \underline{M}_{3A} = 0.05 \cdot l + j \cdot 0.1445 \cdot \log\frac{D_{ek}}{D} \cdot l \equiv \underline{M}_m. \quad (7)$$

Similarly, the remaining own and mutual impedances are calculated $\underline{M}ij = \underline{M}ji$, between the phase conductors of the phases (*i* = *B*, *C*) and the three cable screens (*j* = 1,2,3). For Fig. 2, the single-phase equivalent of Fig. 1 [5] will be:

$$\underline{Z}_e = \frac{\underline{Z}_s + 2 \cdot \underline{Z}_m}{3}, \quad (8)$$

$$\underline{J}_e = \frac{\underline{M}_s + 2 \cdot \underline{M}_m}{\underline{Z}_s + 2 \cdot \underline{Z}_m} \cdot \underline{I}_{KV}, \quad (9)$$

$$\underline{r}_f = \frac{\underline{I}_{KV} - \underline{J}_e}{\underline{I}_{KV}} = 1 - \frac{\underline{J}_e}{\underline{I}_{KV}} = 1 - \frac{\underline{M}_s + 2 \cdot \underline{M}_m}{\underline{Z}_s + 2 \cdot \underline{Z}_m}. \quad (10)$$

When the strings are placed in a plane, it is valid [5]:

$$\underline{Z} = \begin{bmatrix} \underline{Z}_s & \underline{Z}_{m1} & \underline{Z}_{m2} \\ \underline{Z}_{m1} & \underline{Z}_s & \underline{Z}_{m1} \\ \underline{Z}_{m2} & \underline{Z}_{m1} & \underline{Z}_s \end{bmatrix}, \quad (11)$$

$$\underline{Z}_s = (0.05 + r_e + j \cdot 0.1445 \cdot \log\frac{D_{ek}}{d_e/2}) \cdot l, \quad (12)$$

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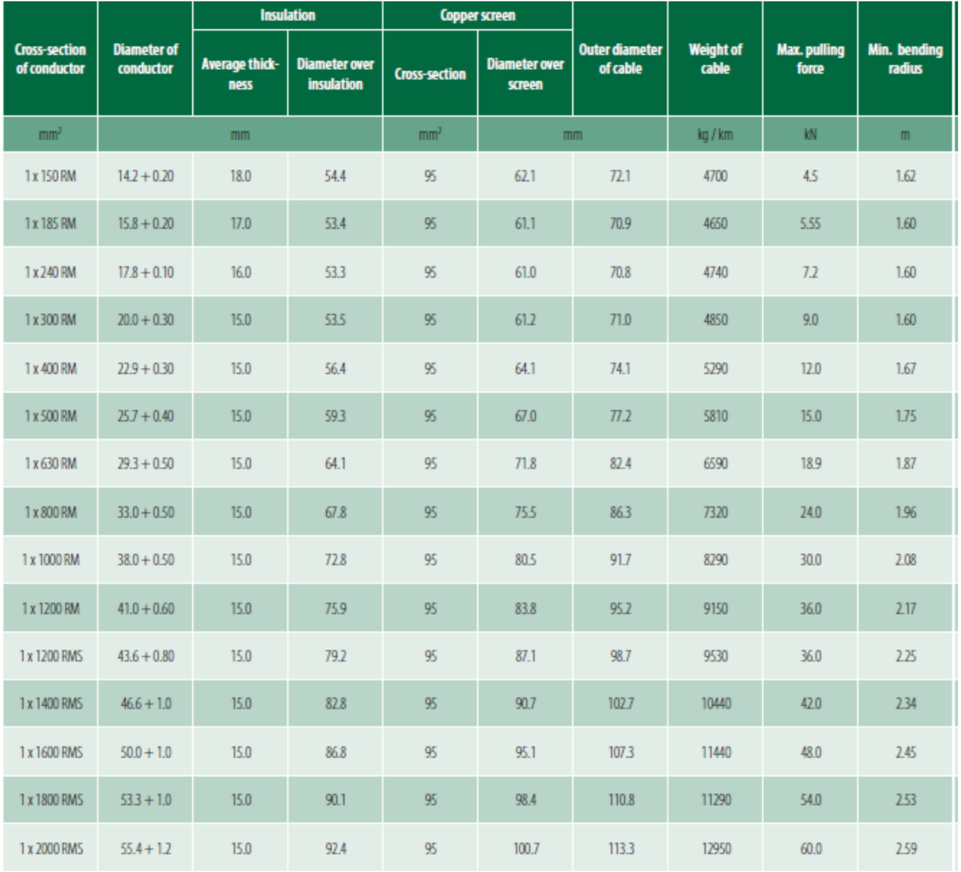
TABLE I

CATALOG DATA FOR POLYETHYLENE CABLES OF THE TYPE NA2XS(FL)2Y U_M=123 KV



Cross-section of conductor	Diameter of conductor	Insulation		Copper screen		Outer diameter of cable	Weight of cable	Max. pulling force	Min. bending radius
		Average thickness	Diameter over insulation	Cross-section	Diameter over screen				
mm²	mm			mm²	mm		kg / km	kN	m
1 x 150 RM	14.2 + 0.20	18.0	54.4	95	62.1	72.1	4700	4.5	1.62
1 x 185 RM	15.8 + 0.20	17.0	53.4	95	61.1	70.9	4650	5.55	1.60
1 x 240 RM	17.8 + 0.10	16.0	53.3	95	61.0	70.8	4740	7.2	1.60
1 x 300 RM	20.0 + 0.30	15.0	53.5	95	61.2	71.0	4850	9.0	1.60
1 x 400 RM	22.9 + 0.30	15.0	56.4	95	64.1	74.1	5290	12.0	1.67
1 x 500 RM	25.7 + 0.40	15.0	59.3	95	67.0	77.2	5810	15.0	1.75
1 x 630 RM	29.3 + 0.50	15.0	64.1	95	71.8	82.4	6590	18.9	1.87
1 x 800 RM	33.0 + 0.50	15.0	67.8	95	75.5	86.3	7320	24.0	1.96
1 x 1000 RM	38.0 + 0.50	15.0	72.8	95	80.5	91.7	8290	30.0	2.08
1 x 1200 RM	41.0 + 0.60	15.0	75.9	95	83.8	95.2	9150	36.0	2.17
1 x 1200 RMS	43.6 + 0.80	15.0	79.2	95	87.1	98.7	9530	36.0	2.25
1 x 1400 RMS	46.6 + 1.0	15.0	82.8	95	90.7	102.7	10440	42.0	2.34
1 x 1600 RMS	50.0 + 1.0	15.0	86.8	95	95.1	107.3	11440	48.0	2.45
1 x 1800 RMS	53.3 + 1.0	15.0	90.1	95	98.4	110.8	11290	54.0	2.53
1 x 2000 RMS	55.4 + 1.2	15.0	92.4	95	100.7	113.3	12950	60.0	2.59

$$\underline{Z}_{m1} = (0.05 + j \cdot 0.1445 \cdot \log \frac{D_{ek}}{D}) \cdot l \, , \qquad (13)$$

$$\underline{Z}_{m2} = (0.05 + j \cdot 0.1445 \cdot \log \frac{D_{ek}}{2D}) \cdot l \, , \qquad (14)$$

$$\underline{M} = \begin{bmatrix} \underline{M}_s & \underline{M}_{m1} & \underline{M}_{m2} \\ \underline{M}_{m1} & \underline{M}_s & \underline{M}_{m1} \\ \underline{M}_{m2} & \underline{M}_{m1} & \underline{M}_s \end{bmatrix} , \qquad (15)$$

$$\underline{M}_s = 0.05 \cdot l + j \cdot 0.1445 \cdot \log \frac{D_{ek}}{d_e / 2} \cdot l \, . \qquad (16)$$

$$\underline{M}_{m1} = 0.05 \cdot l + j \cdot 0.1445 \cdot \log \frac{D_{ek}}{D} \cdot l \, , \qquad (17)$$

$$\underline{M}_{m2} = 0.05 \cdot l + j \cdot 0.1445 \cdot \log \frac{D_{ek}}{2D} \cdot l \, , \qquad (18)$$

$$\underline{Z}_e = \underline{Z}_s - \frac{2 \cdot (\underline{Z}_s - \underline{Z}_{m1})^2}{3 \cdot \underline{Z}_s - 4 \cdot \underline{Z}_{m1} + \underline{Z}_{m2}} , \qquad (19)$$

$$\underline{J}_e = \underline{I}_{KV} \cdot \frac{\underline{Z}_{m2} \cdot \underline{M}_{ml} + \underline{Z}_s \cdot (\underline{M}_s + \underline{M}_{ml} + \underline{M}_{m2})}{\underline{Z}_s^2 - 2 \cdot \underline{Z}_{ml}^2 + \underline{Z}_s \cdot \underline{Z}_{m2}}$$

$$- \underline{I}_{KV} \cdot \underline{Z}_{ml} \cdot \frac{(\underline{M}_s + 2 \cdot \underline{M}_{ml} + \underline{M}_{m2})}{\underline{Z}_s^2 - 2 \cdot \underline{Z}_{ml}^2 + \underline{Z}_s \cdot \underline{Z}_{m2}} \qquad (20)$$

$$\underline{r}_f = 1 - \frac{\underline{Z}_{m2} \cdot \underline{M}_{ml} + \underline{Z}_s \cdot (\underline{M}_s + \underline{M}_{ml} + \underline{M}_{m2})}{\underline{Z}_s^2 - 2 \cdot \underline{Z}_{ml}^2 + \underline{Z}_s \cdot \underline{Z}_{m2}}$$

$$+ \underline{Z}_{ml} \cdot \frac{(\underline{M}_s + 2 \cdot \underline{M}_{ml} + \underline{M}_{m2})}{\underline{Z}_s^2 - 2 \cdot \underline{Z}_{ml}^2 + \underline{Z}_s \cdot \underline{Z}_{m2}} . \qquad (21)$$

II. CALCULATION OF REDUCTION FACTORS FOR DIFFERENT CABLE CROSS SECTIONS

After the calculations made according to the above formulas, the results shown in Table II are obtained. The reduction factor of a bundle of three single-core cables placed in a triangle is smaller than that in a plane from 3.7% to 12% due to the obvious symmetry.

TABLE II

REDUCTION FACTORS OF HV CABLES

Cross section mm^2	Triangle	Plane
2000	$0.066e^{-j81.25^{0}}$	$0.074e^{-j76.72^{0}}$
1600	$0.082e^{-j80.88^{0}}$	$0.088e^{-j75.49^{0}}$
1400	$0.103e^{-j79.35^{0}}$	$0.109e^{-j75.71^{0}}$
1200	$0.139e^{-j77.16^{0}}$	$0.148e^{-j74.27^{0}}$
1000	$0.191e^{-j74.22^{0}}$	$0.198e^{-j74.77^{0}}$

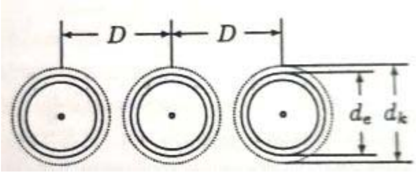


Fig. 3. Configuration plane

III. CALCULATION OF SHORT-CIRCUIT VOLTAGE CONDITIONS IN SUBSTATION CENTRAL

Central substation is connected to the South New substation by two 110 kV cables. The appearance of the circuit is presented in Fig. 4, and in Fig. 5 it's equivalent scheme, taking into account the transposition of the phases.

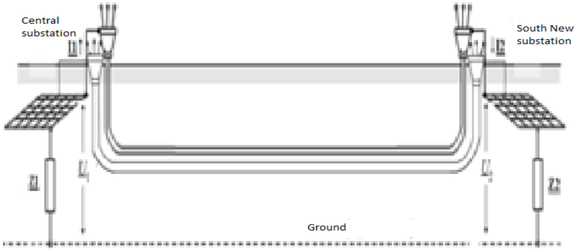


Fig. 4. View of the circuit between Central and South New substation during a short circuit in Central substation

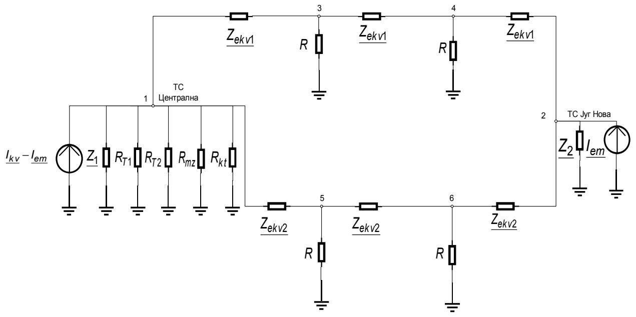


Fig. 5. Equivalent circuit scheme between Centraland South New substation during short circuit in Central substation

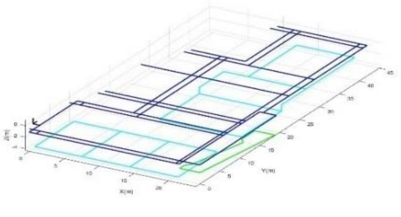


Fig. 6. Appearance of grounding of the Central substation

At 110 kV substation Central are tied, [4], Fig. 6:

- the old grounding of the building with an entrance impedance $\underline{Z}_1$=0.25 Ω,
- the new mesh grounding with grounding resistance R_{mz}=4.508 Ω,
- both thorough grounding with grounding resistance R_{T1}=4.42 Ω and R_{T2}=3.74 Ω,
- the cables tunnel grounding resistance R_{kt}=6.81 Ω
- the first sections of two cables (their equivalent impedances)

The values of the groundings are obtained by computer simulation in Matlab. At the places where the phases of the cables are transposed (nodes 3,4,5,6), groundings are simulated with which the surge arresters are grounded and which are predicted to be at R=5 Ω.

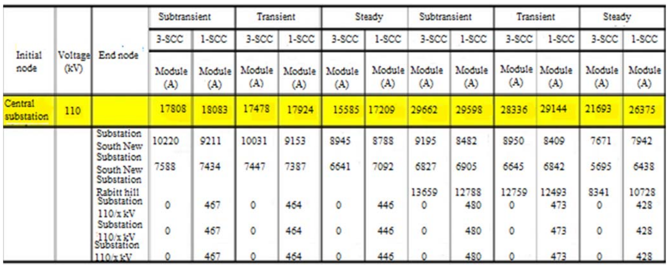
The third sections of the two cables are connected to the grounding of the South New substation and the grounding of the substation which is $\underline{Z}_2$ = 0.18 Ω. It should be emphasized that the EVN services have obtained the data for $\underline{Z}_1$=0.25 Ω and $\underline{Z}_2$=0.18Ω which are the average values of the measurements at several locations at these substations. At the same time, they do not represent grounding resistance of grounding conductors at substations, but input impedances that take into account the input impedances of all MV cables connected to the corresponding substations.

Fig. 5 shows that the network between the Central substation (node 1) and the South New substation (node 2)is composed of 6 nodes. After two additional nodes introduces the transposition of cables to 1/3 of their lengths 2.7 km or 4.11 km respectively, 0.9 km or 1.37 km.It is a non-radial network, so since the input impedance of the system at node 1 substation Central cannot be calculated by simply summing the admittances as in other cases in practice. The system can be solved using the method of independent voltages (potentials in the nodes). For this purpose, the matrix of admits Y with dimensions 6x6 is formed first. Matlab calculates the impedance matrix $\underline{Z} = \underline{Y}^{-1}$, and then calculates the voltage vector in all 6 nodes of the network with the relation (22)

$$\underline{U} = \underline{Z} \cdot \underline{I} . \tag{22}$$

From the power plant operator MEPSO, data were obtained for three-way and single-circuit short-circuit currents of 110 kV busbars in substation 110/35/10 (20) kV "Central".

TABLE III



Initial node	Voltage (kV)	End node	Subtransient		Transient		Steady		Subtransient		Transient		Steady	
			3-SCC	1-SCC	3-SCC	1-SCC	3-SCC	1-SCC	3-SCC	1-SCC	3-SCC	1-SCC	3-SCC	1-SCC
			Module (A)	Module (A)	Module (A)	Module (A)	Module (A)	Module (A)	Module (A)	Module (A)	Module (A)	Module (A)	Module (A)	Module (A)
Central substation	110		17808	18083	17478	17924	15585	17209	29662	29598	28336	29144	21693	26375
		Substation South New	10220	9211	10031	9153	8945	8788	9195	8482	8950	8409	7671	7942
		Substation South New	7588	7434	7447	7387	6641	7092	6827	6905	6645	6842	5695	6438
		Substation Rabitt hill							13659	12788	12759	12493	8341	10728
		Substation 110/x kV	0	467	0	464	0	446	0	480	0	473	0	428
		Substation 110/x kV	0	467	0	464	0	446	0	480	0	473	0	428
		Substation 110/x kV	0	467	0	464	0	446	0	480	0	473	0	428

According to [4], first the currents that are injected into the grounding systems of the Central substation and South New substation are calculated, and then the voltages of the respective groundings, according to the relation (22).

[1)] Triangle configuration, cross section 2000 mm^2

$$\underline{Y}=\begin{bmatrix} 5.309-j2.986 & 0+j0 & -0.269+j1.802 & 0+j0 & -0.178+j1.184 & 0+j0 \\ 0+j0 & 6.002-j2.986 & 0+j0 & -0.269+j1.802 & 0+j0 & -0.178+j1.184 \\ -0.269+j1.802 & 0+j0 & 0.737-j3.603 & -0.269+j1.802 & 0+j0 & 0+j0 \\ 0+j0 & -0.269+j1.802 & -0.269+j1.802 & 0.737-j3.603 & 0+j0 & 0+j0 \\ -0.178+j1.184 & 0+j0 & 0+j0 & 0+j0 & 0.555-j2.386 & -0.178+j1.184 \\ 0+j0 & -0.178+j1.184 & 0+j0 & 0+j0 & -0.178+j1.184 & 0.555-j2.386 \end{bmatrix}$$

$$\underline{Z}=\begin{bmatrix} 0.180+j0.034 & 0.010-j0.028 & 0.121+j0.002 & 0.064-j0.016 & 0.118-j0.002 & 0.061-j0.020 \\ 0.010-j0.028 & 0.160+j0.026 & 0.057-j0.018 & 0.108-j0.004 & 0.055-j0.021 & 0.105-j0.006 \\ 0.121+j0.002 & 0.057-j0.018 & 0.181+j0.336 & 0.126+j0.111 & 0.093-j0.018 & 0.072-j0.023 \\ 0.064-j0.016 & 0.108-j0.001 & 0.126+j0.151 & 0.174+j0.342 & 0.072-j0.023 & 0.087-j0.019 \\ 0.118-j0.002 & 0.055-j0.021 & 0.093-j0.018 & 0.072-j0.023 & 0.236+0.492 & 0.160+j0.219 \\ 0.061-j0.020 & 0.105-j0.006 & 0.072-j0.023 & 0.087-j0.019 & 0.160+j0.219 & 0.230+j0.491 \end{bmatrix}$$

$$\underline{U}=\begin{bmatrix} \underline{U}_{CN} \\ \underline{U}_{JN} \\ \underline{U}_3 \\ \underline{U}_4 \\ \underline{U}_5 \\ \underline{U}_6 \end{bmatrix}=\begin{bmatrix} 294.6e^{-j65} \\ 2708.7e^{j5.66} \\ 969e^{-j13.01} \\ 1803.2e^{-j2.32} \\ 937.9e^{-j16.83} \\ 1756.2e^{-j4.62} \end{bmatrix}$$

[2)] Configuration plane, cross section 2000 mm^2

$$\underline{Y}=\begin{bmatrix} 5.351-j3.12 & 0+j0 & -0.295+j1.884 & 0+j0 & -0.194+j1.235 & 0+j0 \\ 0+j0 & 6.044-j3.12 & 0+j0 & -0.295+j1.884 & 0+j0 & -0.194+j1.235 \\ -0.295+j1.184 & 0+j0 & 0.789-j3.759 & -0.295+j1.884 & 0+j0 & 0+j0 \\ 0+j0 & -0.295+j1.884 & -0.295+j1.884 & 0.789-j3.769 & 0+j0 & 0+j0 \\ -0.194+j1.235 & 0+j0 & 0+j0 & 0+j0 & 0.588-j2.471 & -0.194+j1.235 \\ 0+j0 & -0.194+j1.235 & 0+j0 & 0+j0 & -0.194+j1.235 & 0.588-j2.471 \end{bmatrix}$$

$$\underline{Z}=\begin{bmatrix} 0.178+j0.034 & 0.111-j0.029 & 0.121+j0.003 & 0.064-j0.016 & 0.119-j0.002 & 0.062-j0.020 \\ 0.011-j0.029 & 0.159+j0.027 & 0.058-j0.018 & 0.107-j0.001 & 0.056-j0.021 & 0.106-j0.006 \\ 0.120+j0.003 & 0.058-j0.018 & 0.178+j0.321 & 0.124+j0.144 & 0.094-j0.017 & 0.073-j0.023 \\ 0.064+j0.016 & 0.107-j0.001 & 0.124+j0.144 & 0.171+j0.319 & 0.073-j0.023 & 0.088-j0.019 \\ 0.119-j0.002 & 0.056-j0.021 & 0.094-j0.017 & 0.073-j0.023 & 0.236+j0.475 & 0.161+j0.212 \\ 0.062-j0.020 & 0.106-j0.006 & 0.073-j0.023 & 0.088-j0.019 & 0.161+j0.212 & 0.230+j0.474 \end{bmatrix}$$

$$\underline{U}=\begin{bmatrix} \underline{U}_{CN} \\ \underline{U}_{JN} \\ \underline{U}_3 \\ \underline{U}_4 \\ \underline{U}_5 \\ \underline{U}_6 \end{bmatrix}=\begin{bmatrix} 299.2e^{-j59.49} \\ 2680.5e^{j5.4} \\ 976.5e^{-j12.54} \\ 1793.7e^{-j2.28} \\ 962.8e^{-j16.4} \\ 1768e^{-j4.77} \end{bmatrix}$$

[3)] Triangle configuration, cross section 1600 mm^2

$$\underline{Y}=\begin{bmatrix} 5.355-j2.971 & 0+j0 & -0.297+j1.792 & 0+j0 & -0.195+j1.178 & 0+j0 \\ 0+j0 & 6.048-j2.97 & 0+j0 & -0.297+j1.792 & 0+j0 & -0.195+j1.178 \\ -0.297+j1.792 & 0+j0 & 0.794-j3.585 & -0.297+j1.792 & 0+j0 & 0+j0 \\ 0+j0 & -0.297+j1.792 & -0.297+j1.792 & 0.794-j3.585 & 0+j0 & 0+j0 \\ -0.195+j1.178 & 0+j0 & 0+j0 & 0+j0 & 0.59-j2.356 & -0.195+j1.178 \\ 0+j0 & -0.195+j1.178 & 0+j0 & 0+j0 & -0.195+j1.178 & 0.59-j2.356 \end{bmatrix}$$

$$\underline{Z}=\begin{bmatrix} 0.179+j0.033 & 0.010-j0.028 & 0.121+j0.002 & 0.064-j0.016 & 0.119-j0.003 & 0.062-j0.020 \\ 0.010-j0.028 & 0.160+j0.026 & 0.057-j0.018 & 0.107-j0.002 & 0.055-j0.021 & 0.105-j0.006 \\ 0.121+j0.002 & 0.057-j0.018 & 0.186+j0.334 & 0.129+j0.150 & 0.094-j0.018 & 0.073-j0.024 \\ 0.064-j0.016 & 0.107-j0.002 & 0.129+j0.150 & 0.179+j0.333 & 0.073-j0.024 & 0.087-j0.020 \\ 0.119-j0.003 & 0.055-j0.021 & 0.094-j0.018 & 0.073-j0.024 & 0.249+j0.494 & 0.168+j0.220 \\ 0.062-j0.020 & 0.105-j0.006 & 0.073-j0.024 & 0.087-j0.020 & 0.168+j0.220 & 0.243+j0.493 \end{bmatrix}$$

$$\underline{U}=\begin{bmatrix} \underline{U}_{CN} \\ \underline{U}_{JN} \\ \underline{U}_3 \\ \underline{U}_4 \\ \underline{U}_5 \\ \underline{U}_6 \end{bmatrix}=\begin{bmatrix} 247.05e^{-j66.2} \\ 2705.45e^{j4.45} \\ 959.56e^{-j12.28} \\ 1798.14e^{-j2.96} \\ 945.14e^{-j16.29} \\ 1772.27e^{-j5.54} \end{bmatrix}$$

[4)] Configuration plane, cross section 1600 mm^2

$$\underline{Y}=\begin{bmatrix} 5.409-j3.098 & 0+j0 & -0.332+j1.871 & 0+j0 & -0.214+j1.227 & 0+j0 \\ 0+j0 & 6.102-j3.098 & 0+j0 & -0.332+j1.871 & 0+j0 & -0.214+j1.227 \\ -0.332+j1.871 & 0+j0 & 0.865-j3.743 & -0.332+j1.871 & 0+j0 & 0+j0 \\ 0+j0 & -0.332+j1.871 & -0.332+j1.871 & 0.865-j.3.743 & 0+j0 & 0+j0 \\ -0.214+j1.227 & 0+j0 & 0+j0 & 0+j0 & 0.628-j2.454 & -0.214+j1.227 \\ 0+j0 & -0.214+j1.227 & 0+j0 & 0+j0 & -0.214+j1.227 & 0.628-j2.454 \end{bmatrix}$$

$$\underline{Z}=\begin{bmatrix} 0.178+j0.034 & 0.011-j0.028 & 0.120+j0.003 & 0.064-j0.016 & 0.118-j0.003 & 0.062-j0.020 \\ 0.011-j0.028 & 0.159+j0.026 & 0.058-j0.018 & 0.100-j0.001 & 0.056-j0.021 & 0.105-j0.006 \\ 0.120+j0.003 & 0.058-j0.018 & 0.185+j0.319 & 0.127+j0.143 & 0.094-j0.017 & 0.073-j0.023 \\ 0.064-j0.016 & 0.107-j0.001 & 0.127+j0.143 & 0.178+j0.318 & 0.073-j0.023 & 0.087-j0.019 \\ 0.118-j0.003 & 0.056-j0.021 & 0.094-j0.017 & 0.073-j0.023 & 0.244+j0.474 & 0.164+j0.210 \\ 0.062-j0.020 & 0.105-j0.006 & 0.073-j0.023 & 0.087-j0.019 & 0.164+j0.210 & 0.238+j0.473 \end{bmatrix}$$

$$\underline{U}=\begin{bmatrix} \underline{U}_{CN} \\ \underline{U}_{JN} \\ \underline{U}_3 \\ \underline{U}_4 \\ \underline{U}_5 \\ \underline{U}_6 \end{bmatrix}=\begin{bmatrix} 262.1e^{-j53.03} \\ 2670.6e^{j4.48} \\ 972.5e^{-j11.57} \\ 1878e^{-j2.73} \\ 958.4e^{-j15.36} \\ 1763.7e^{-j5.18} \end{bmatrix}$$

IV. CONCLUSION

1. The reduction factor of a bundle of three single-core cables placed in a triangle is smaller than that in a plane from 3.7% to 12% due to the obvious symmetry.
2. On the one hand, smaller reduction factors contribute to reducing the voltage in the Central substation and thus relieving its grounding, but on the other hand they contribute to increasing the transferred potential in the South New substation and increasing the risks of excessive touch and step voltages in and around the South New substation.
3. When choosing a HV cable, it is necessary to choose the optimal configuration in terms of meeting the criteria for safety in and around both substations.

REFERENCES

[1] HD637 S1: Power Instalations Exceeding 1 kV AC, 1999.

[2] J. Nahman, "Neutral Grounding in Power Distribution Networks", Naucna kniga, Belgrade, 1980 (in Serbian).

[3] J. Nahman, V. Mijailović, "High Voltage Power Stations", Academic Mind, Belgrade, 2005 (in Serbian).

[4] New substation 110/35/10 (20) kV Central, book 5, grounding, Basic project, TIMEL, Nikolce Acevski, 2019.

[5] R. Ackovski, M. Todorovski, *Groundings and Grounding Systems in Power Networks*, Skopje, 2017.