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UZEMLJENJE VISOKONAPONSKE TRAFOSTANICE U NEPOVOLJNIM USLOVIMA

GROUNDING OF A HIGH VOLTAGE SUBSTATION IN UNFAVORABLE CONDITIONS

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KRATAK SADRŽAJ

Cilj rada je pružiti detaljan pregled procesa planiranja uzemljenja visokonaponske trafostanice u nepovoljnim uslovima. Konkretno, rad obuhvata osnove projektovanja mrežastog uzemljenja za sve vrste visokonaponskih trafostanica, proces definisanja oblika mrežastog uzemljenja, izračunavanje otpornosti uzemljenja, kao i izračunavanje maksimalnih napona dodira i koraka koji se javljaju u različitim situacijama. Mrežasto uzemljenje trafostanice je dizajnirano pomoću aplikacije razvijene na programskoj platformi MATLAB, koja prikazuje trodimenzionalnu prezentaciju mrežastog uzemljenja, i vizuelnu prezentaciju rezultata. Pored mrežastog uzemljenja, prilikom projektovanja sistema uzima se u obzir i sistem uzemljenja temelja trafostanice, kao i veze sa kablovima i sistem uzemljenja susedne trafostanice. Kablovi koji povezuju obe trafostanice imaju sprovodni plašt, što doprinosi smanjenju napona dodira i koraka posmatrane trafostanice kao rezultet izvoza potencijala kroz sprovodni plašt. Koliko je redukcioni faktor tih kablova manji toliko je veci izvoz potencijala. Sistem je dizajniran u suboptimalnim uslovima. Sa jedne strane planirane trafostanice nalazi se postojeća zgrada u vlasništvu kompanije koja će imati trafostanicu, a sa druge strane nalazi se ambasada. Ova topologija sprečava izgradnju zemljane mreže na konvencionalan način, iz razloga što je trafostanica veoma blizu ambasadi. Situacija zahteva primenu nekonvencionalnog pristupa, uzimajući u obzir da naponi dodira i koraka ne smeju biti premašeni, odnosno uslovi bezopasnosti moraju biti zadovoljeni.

Ključne reči: uzemljenje trafostanice, mrežasto uzemljenje

ABSTRACT

The goal of the paper is to give a detailed overview of the process of planning the grounding of a high voltage (HV) substation in unfavorable conditions. More specifically, the paper covers the foundations of designing a ground grid for all types of HV substations, the process of defining the form of the ground grid, the calculation of the grounding resistivity, as well as calculating the maximum touch and step voltages that occur in different situations.

The ground grid of the substation is designed using an application developed in the programming platform MATLAB, which shows a three-dimensional representation of the ground grid, and a visual representation of the results. In addition to the ground grid, the grounding system of the substation foundation, the cable connection, and the grounding system of a neighboring substation are taken into consideration when designing the system. The cables connecting the two substations have a conductive screen with a small reduction factor, which as a result of the potential drain from the conductive screen, contributes to the reduction of the touch and step voltages of the observed substation. A smaller reduction factor results in increased potential drain via the conductive screen.

The system is designed in sub-optimal conditions. On one side of the planned substation there is an existing building owned by the utility company that will own the substation as well, and on the other side an embassy is situated. This topology prevents the construction of the grounding grid in a conventional way, the reason being that the substation would be very close to the embassy. The situation requires taking an unconventional approach, while taking into consideration that the maximum tolerable grounding resistivity, touch and step voltage should not be crossed.

Key words: Substation grounding, Ground grid, Touch voltage, Step voltage, Cable reduction factor.

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1. INTRODUCTION

By definition, grounding is considered as a set of measures taken, in order to achieve normal working conditions in the power system, a safe work environment, as well as a safe environment for the people and other animals in the vincinity of the buildings and objects which can be potentially life-threatening in normal or emergency conditions [1].

Although it's a practice that has not changed significantly over the course of time, there has been extensive research in the area of modeling and analysis of grounding systems. The use of various commercially available software for grounding design and analysis has certainly contributed to the research on this topic, enabling engineers to model the conditions under which the grounding needs to be designed, as well as freely test and optimize the model of the ground grid [2]. In addition, the rapid development in the area of Artificial Intelligence has also assisted in further improving the methodologies used in designing grounding systems. Solutions to optimal ground grid design have been achieved using models created by use of Genetic Algorithms and Pattern Search [3]. As it is the case with many of the situations when the design of a ground grid is involved, complex or unfavourable conditions may hinder the process of finding the optimal solution for a grounding system. Research has been done in this area as well, where intricate methods have been proposed that assist in the assesment of the influence of conditions, such as grounding grid and soil module resistivity, on surface potential [4].

Even though technology these days allows engineers to find a grounding solution with minimal input from the user's side thanks to all the advancements, often times engineers find themselves facing a problem that they need to approach in a standard way. This means that the optimal solution is acquired using an experimental and iterative process, and not necessarily solved using an optimization algorithm.

The goal of the paper is to cover this type of situation. It aims to give a detailed overview of the process of planning the grounding of a HV substation in unfavorable conditions. More specifically, the paper covers the foundations of designing a ground grid for all types of HV substations, the process of defining the form of the ground grid, the calculation of the grounding resistivity, as well as calculating the maximum touch and step voltages that occur in different situations. The modeling process was assisted by the use of a software developed in the programming platform MATLAB, which shows a three-dimensional representation of the ground grid, and a visual representation of the results.

2. CHAPTERS

2.1 Methodology

2.1.1 Characteristics of a grounding system - There are a number of empiric and semi-empiric equations that can be used to calculate the characteristics of a grounding system. A list of the most frequently used equations in the design practice are listed in [1]. Most of the equations listed there are used when the soil is considered homogenous. Some of the more useful equations however, applicable in more realistic situations, are used if the ground grid is placed in a soil which consists of two layers with different resistances ρ_1 and ρ_2, where the upper layer has a depth of H.

$$R_z = 0{,}13 \cdot \frac{\rho}{\sqrt{A}} \log_{10}\left(\frac{2400 \cdot \sqrt{A}}{N}\right) \cdot \left(1 - 0{,}45 \cdot \frac{l_S}{\sqrt{A}}\right), \quad \frac{l_S}{\sqrt{A}} \leq 0{,}2 \tag{2.1.1}$$

$$R_Z^{(n)} = \left(\frac{\rho_2}{\rho_1}\right)^x \cdot R_z \tag{2.1.2}$$

$$x = 0{,}14 \cdot \log\left(\frac{44N\sqrt{A}}{H^2}\right); \quad 0{,}2 \leq \frac{\rho_2}{\rho_1} \leq 1 \tag{2.1.3}$$

$$x = 0{,}12 \cdot \log\left(3160N\sqrt{A}\right) - 0{,}2 \cdot \log H \cdot \log\frac{1000}{\sqrt{A}}; \quad 1 \leq \frac{\rho_2}{\rho_1} \leq 5 \tag{2.1.4}$$

$$R_Z^{(n)} = \left(\frac{\rho_2}{\rho_1}\right)^{0{,}76} \cdot R_z; \quad \rho_2 < \rho_1 \tag{2.1.5}$$

Where R_z is the resistance of the ground grid in homogenous soil, A is the area of the ground grid [m^2], N is the number of meshes in the ground grid, l_S is the length of a single probe (vertical conductor) [m]. $R_z^{(n)}$ is the resistance of ground grid, placed in unhomogenous soil, and H the depth of upper layer of soil with resistance ρ_1. Equations (2.1.6 – 2.1.9) are used for calculating maximum touch and step potentials:

$$E_m^{(n)} = \left(\frac{\rho_2}{\rho_1}\right)^x \cdot E_m \tag{2.1.6}$$

$$x = 0{,}042 \cdot \log(3{,}53 \cdot H) \cdot (\log N)^2 - \frac{1}{2} \cdot \log\frac{H}{6}; \quad \rho_2 < \rho_1 \tag{2.1.7}$$

$$x = 0{,}12 \cdot \log\left(N \cdot \sqrt{A}\right) - 0{,}16 \cdot \log(4{,}6 \cdot H); \quad \rho_2 > \rho_1 \tag{2.1.8}$$

$$E_c^{(n)} = \left[1 + 0{,}7 \cdot \log\left(\frac{\rho_2}{\rho_1}\right)\right] \cdot E_c \tag{2.1.9}$$

Where $E_m^{(n)}$ and $E_c^{(n)}$ are the maximum touch and step potentials.

2.1.2 Safety criteria – The calculated touch and step voltages are compared to the permissible values set according to standards. In general, the permissible values are dependent on the fault duration t_f. The grounding design is said to be acceptable when the following criteria are met:

$$\begin{aligned} U_t &\le U_{tp} \\ U_s &\le U_{sp} \end{aligned} \tag{2.1.10}$$

Where U_t and U_s are the highest calculated touch and step voltages, U_{tp} and U_{sp} the maximum permissible touch and step voltages.

Modern European standards, such as [5], which currently apply in the Republic of North Macedonia, consider only the permissible touch voltage. This is acceptable; taking into account, that touch voltage always poses a higher risk than step voltage, which is why the permissible touch voltages are always lower than the permissible step voltages.

The current standard [5], describes the method of calculating the permissible touch voltage. Its value depends on the duration of the fault, the body current limit, heart current factor, body impedance and body factor. Figure 2.1 shows the permissible touch voltage as a function of the fault duration.

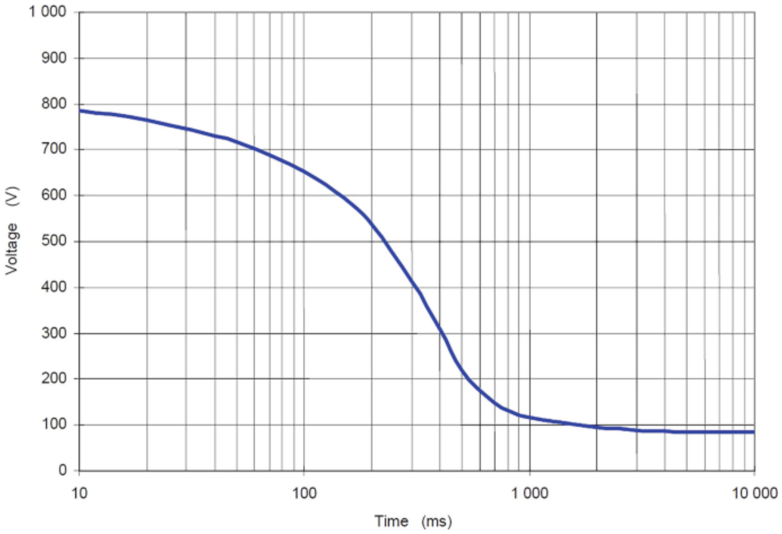


Figure 2.1 - Permissible touch voltages [5]

Table 2.1 shows some calculated values of the permissible touch voltages, also taken from [5].

Table 2.1 - Calculated values of the permissible touch voltages as a function of fault duration [5]

Fault duration [s]	Permissible touch voltage [V]
0,05	716
0,10	654
0,20	537
0,50	220
1,00	117
2,00	96
5,00	86
10,00	85

2.1.3 Design procedure of grounding system – The current standard [5], describes a systematic procedure of designing a grounding system, which is as follows:

a) Data collection, e.g. ground fault current, fault duration and layout;
b) Initial design of the grounding system based on the functional requirements;
c) Determine if it is part of a global grounding system;
d) If not, determine soil characteristics e.g. specific soil resistivity of layers;
e) Based on ground fault current, determine the current discharged into soil from grounding system;
f) Based on layout, soil characteristics and parallel grounding systems, determine the overall impedance to ground
g) Determine ground potential rise
h) Determine permissible touch voltage;
i) If the ground potential rise is below the permissible touch voltage, the design is complete

If the criteria haven't been met, proper measures should be taken to lower the ground potential rise. Once the criteria have been met, the design can be refined if necessary.

2.2 Case study

The subject of the study is the grounding of a 110/35/10(20) kV substation "Centralna", located in the city of Skopje. The substation is built in a limited space, which prevents the design of a conventional ground grid that would cover all of the buildings in the substation, as well as a contour one meter around the ground grid. The reason behind the spatial constraints is that the substation is being built in the vicinity of an embassy building. Besides the embassy, on the other side of the substation there is an existing medium voltage substation belonging to a utility company. Figure 2.2 shows the location of the old substation, the embassy and the substation "Centralna", which is the subject of the study.

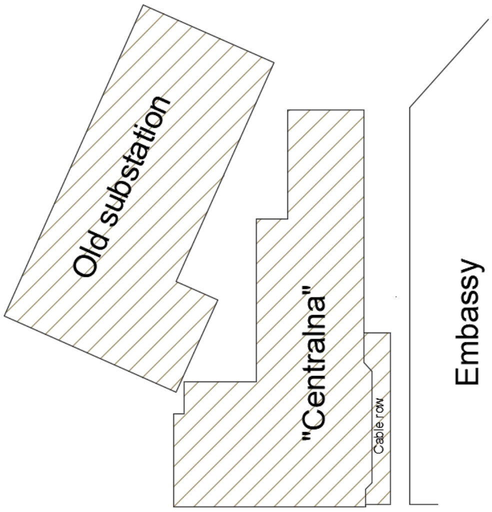
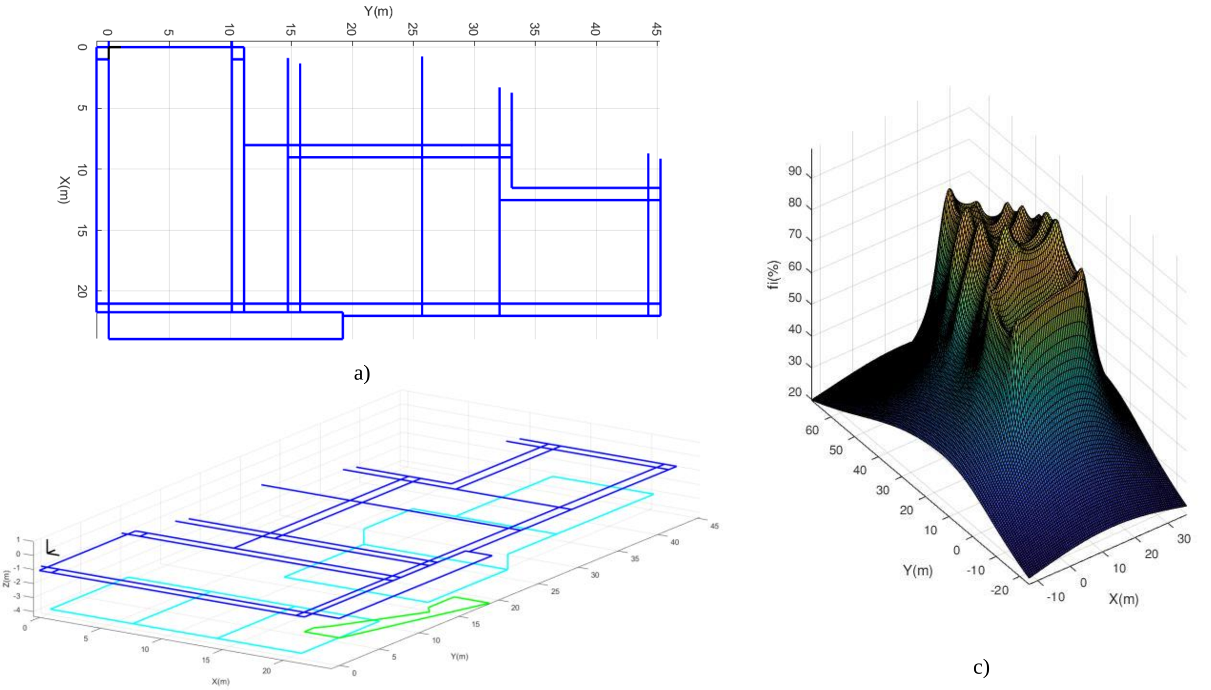


Figure 2.2 - Location of the substation

2.2.1 Ground grid design – Considering the layout of the substation, an initial ground grid design was conceived, which was later refined in order to get to the final design. The ground grid of the substation is placed at a depth of 1 meter. The ground grid is also connected to the grounding system of the substation foundation, as well as the grounding of the cable row adjacent to the substation. This lowers the grounding resistance, and with that the ground potential rise as well.

The modeling of the ground grid, along with all of the corresponding calculations, was done using an application developed in the programming platform MATLAB. The application allows a 3D overview of the designed grounding system, a 3D representation of the ground potential rise in the area, the maximum touch and step voltages, along with the potential rise in arbitrary points chosen by the user. After a number of iterations, the final design shown in Figure 2.3 a) was achieved. A 3D representation of the ground grid (blue), foundation grounding (cyan) and cable row grounding (green) together is shown in Figure 2.3 b). A 3D representation of the earth potential rise around the ground grid is shown in Figure 2.3 c).



a)

b)

c)

Figure 2.3 - a) Ground grid design; b) Ground grid (blue), foundations (cyan) and cable row (green) grounding; c) ground potential rise (%)

The calculated resistances of the ground grid R_z, foundation grounding R_T and cable row grounding R_{kt} using the software are shown in (2.2.1). The foundation grounding consists of two parts, R_{T1} and R_{T2}.

$$
\begin{aligned}
&R_z = 4{,}508\Omega \\
&R_{T1} = 4{,}417\Omega, \quad R_{T2} = 3{,}737\Omega \\
&R_{kt} = 6{,}81\Omega
\end{aligned}
\tag{2.2.1}
$$

2.2.2 Grounding system equivalent circuit – The substation in the case study is connected via two systems of power cables, 3 x NA2XS(FL)2Y 1600/95 (64)110-115(123) kV, to a neighboring substation “Jug Nova”. The grounding resistance of this substation and the impedances of the two connecting cables need also be taken into account in the case of a short circuit, as it would contribute in the increase of the short circuit current.

In order to calculate the earth potential rise at the substation “Centralna”, the entirety of the grounding system has to be considered. Figure 2.4 shows the equivalent circuit of the grounding system between “Centralna” and the neighboring “Jug Nova”.

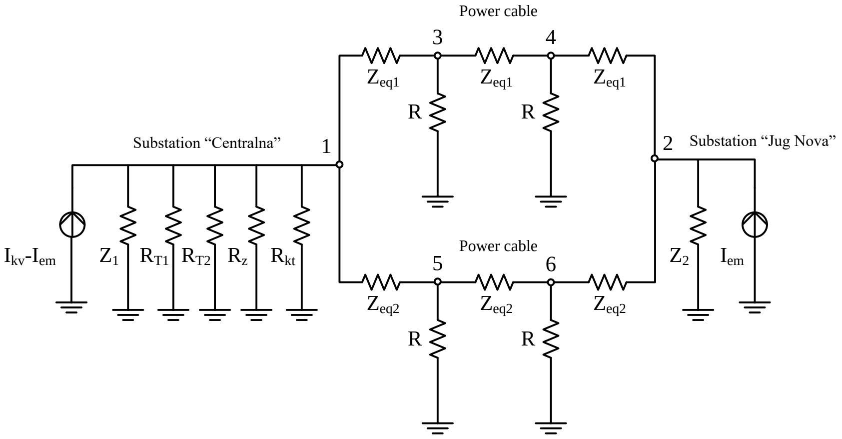


Figure 2.4 - Equivalent circuit of grounding system

In Figure 2.4, node 1 represents the substation "Centralna", node 2 the substation "Jug Nova". Node 3, 4, 5 and 6 are positions at which the power cables are transposed (at 1/3 of the length of the cable). Later in the case study, three cases will be observed at the points of transposition: no grounding ($R = \infty$), grounding in the form of a square contour ($R = 5\ \Omega$), and grounding in the form of a single conductor ($R = 15.84\ \Omega$). $\underline{I}_{kv} - \underline{I}_{em}$ denotes the short circuit current feed from the substation "Centralna", $\underline{Z}_1$ is the grounding impedance of the substation's old building. $\underline{Z}_{eq1}$ and $\underline{Z}_{eq2}$ are the impedances of the sections of each power cable. $\underline{Z}_2$ is the grounding impedance of the substation "Jug Nova". The utility company which owns "Jug Nova" has given information that $\underline{Z}_2 = 0{,}18\Omega$. I_{em} is the short circuit current feed from "Jug Nova".

The two power cables connecting "Centralna" and "Jug Nova" have lengths of 2,7km and 4,11km accordingly. As mentioned, each of the cables are transposed on two locations across their length, at approximately 1/3 of their lengths. That length would be 0,9km for the first, and 1,37km for the second cable. This means that each cable can be represented in 3 sections, with each section having the same impedance.

$\underline{Z}_{eq1}$ and $\underline{Z}_{eq2}$ of each section are calculated by equating the three separate protective screens of each phase conductor with one. The impedance of each section per kilometer can be calculated using the formula [1]:

$$\underline{Z}_{eq} = \left(0{,}05 + \frac{r_e}{3} + j0{,}1445 \cdot \log\frac{D_{ek}}{D_s}\right) = (0{,}09 + j0{,}602)\frac{\Omega}{km} \tag{2.2.2}$$

Where $r_e = 0{,}12\Omega/\text{km}$ is the series resistance of metal screening of a single-phase conductor, $D_{ek} = 1611{,}76\text{m}$ is the equivalent distance of the feedback loop of the current via the soil. $D_s = 0{,}1089\text{m}$ is the mean geometric distance between the screens of each conductor placed in a triangular formation.

Considering the section lengths of each cable, the following values for $\underline{Z}_{eq1}$ and $\underline{Z}_{eq2}$ are acquired:

$$\begin{aligned}\underline{Z}_{eq1} &= (0{,}09 + j0{,}602) \cdot 0{,}9 = (0{,}08 + j0{,}536)\Omega \\ \underline{Z}_{eq2} &= (0{,}09 + j0{,}602) \cdot 1{,}37 = (0{,}123 + j0{,}823)\Omega\end{aligned} \tag{2.2.3}$$

2.2.3 Cable reduction factor – The reduction factor of the cable is an indicator for how much of the total fault current will be injected into the ground grid, if a fault occurs on the end of the cable. The reduction factor $\underline{r}_f$ is calculated using the equation:

$$\underline{r}_f = 1 - \frac{\underline{M}_s + 2 \cdot \underline{M}_m}{\underline{Z}_s + 2 \cdot \underline{Z}_m} = (0{,}01 + j0{,}065) = 0{,}066e^{j81{,}25} \tag{2.2.4}$$

Where $\underline{Z}_s$ and $\underline{Z}_m$ are the self-impedance of a single conductor and mutual impedance between two conductors accordingly, whereas $\underline{M}_s$ and $\underline{M}_m$ are the mutual impedances between the phase conductor and cable screen of each separate conductor.

2.2.4 Earth potential rise in case of short circuit at "Centralna" – Data about three-phase and single-phase short circuit currents on the high voltage side was acquired by the system operator in order to determine the potential rise in the worst case scenario. Table 2.2 shows this data.

Table 2.2 - Data for injected current at "Centralna", in case of three-phase and single-phase fault at "Centralna"

Start node	**End node**	**Sub-transient**		**Transient**		**Steady**	
		3-phase	**1-phase**	**3-phase**	**1-phase**	**3-phase**	**1-phase**
		Modulus [A]	**Modulus [A]**	**Modulus [A]**	**Modulus [A]**	**Modulus [A]**	**Modulus [A]**
Centralna		17808	18038	17478	17924	15585	17209
	Centralna	10220	9211	10031	9153	8945	8788
	Jug Nova	7588	7434	7447	7387	6641	7092
	TR 110/x kV	0	467	0	464	0	446
	TR 110/x kV	0	467	0	464	0	446
	TR 110/x kV	0	467	0	464	0	446

From Table 2.2 it can be noticed that the largest value for the fault current is in the case of a single-phase fault at the 110kV side at "Centralna", for the sub-transient period (18,038kA).

Taking into account the reduction factor of the two power cables, the injected current into the ground grid of "Centralna" would be:

$$\underline{I}_{zsc} = \underline{I}_{kv1} + \underline{I}_{kv2} - \left(\underline{J}_{e1} + \underline{J}_{e2}\right) = 1094{,}65 e^{j81{,}25} A \tag{2.2.5}$$

Where $\underline{I}_{kv1}$ and $\underline{I}_{kv2}$ are the total fault currents injected from "Centralna" and "Jug Nova" accordingly, $\underline{J}_{e1}$ and $\underline{J}_{e2}$ are the portions of the fault current injected into the neighboring "Jug Nova", which can be calculated using the reduction factor of the power cables. Thus, the injected current into the ground grid of "Jug Nova" in this case would be:

$$\underline{I}_{zsjn} = \underline{J}_{e1} + \underline{J}_{e2} = \left(1 - \underline{r}_f\right) \cdot \left(\underline{I}_{kv1} + \underline{I}_{kv2}\right) = 16514{,}03 e^{-j3{,}76} A \tag{2.2.6}$$

Using the values $\underline{I}_{zsc}$ and $\underline{I}_{zsjn}$, as well as a matrix of impedances formed according to Figure 2.4, the voltage at each node of the network is calculated. While doing so, three different cases were analyzed regarding the grounding at the points of transposition of the power cables:

1. The transposition points aren't grounded (R = ∞), nodes 3, 4, 5 and 6 are ignored;
2. The transposition points are grounded in the form of a square contour (R = 5Ω);
3. The transposition points are grounded via a single metal conductor (R = 15,84 Ω).

Table 2.3 shows the grounding voltage, maximum touch and step voltages for all three cases, that occur at all the possible locations in the case of a single-phase fault at „Centralna".

Reading from Table 2.3, it can be noted that the touch and step voltage values at the substation „Centralna" are within the permissible limits. The same cannot be said when observing the neighboring station however, as for this location the permissible touch voltages are only within the limits for a fault duration of 0,1s.

The issue could be solved if asphalt is poured on the surface around the substation, which would lower the maximum touch voltages in all cases.

Regarding the locations at which the transposition of the power cables are performed, there is no equipment which a bystander can accidentally touch, so there is no danger of a high touch voltage. There is also no data about the soil resistance at these locations, however looking at the values for the maximum step potential, there would be no issue either way.

Table 2.3 - Grounding voltage, touch voltage and step voltage that occur at different locations for single-phase fault at „Centralna“.

Observed location	Case	Grounding voltage U_z [V]	Max. touch potential E_t [V]	Max. step potential E_s [V]	Surface not treated		Asphalt on surface: ρ_s=10000Ωm	
					Max touch voltage U_t [V]	Max step voltage U_s [V]	Max touch voltage U_t [V]	Max step voltage U_s [V]
„Centralna“ (ρ=500Ωm)	1	369,4	111,2	36,57	62,54	9,14	6,95	0,60
	2	310,2	93,34	30,71	53,34	7,68	5,83	0,50
	3	346,7	104,3	34,32	59,60	8,58	6,52	0,56
„Jug Nova“ (ρ=287Ωm)	1	2809,4	842,8	280,9	633,7	122,1	52,68	4,6
	2	2704,5	811,4	270,5	610,1	117,6	50,71	4,4
	3	2772,5	831,8	277,3	625,4	120,6	51,99	4,55
Transposition (node 3) (ρ – no data)	1	node missing in this case						
	2	968,4	/	28,1	/	/	/	/
	3	1049,5	/	45,13	/	/	/	/
Transposition (node 4) (ρ – no data)	1	node missing in this case						
	2	1800,1	/	25,2	/	/	/	/
	3	1895,8	/	81,52	/	/	/	/
Transposition (node 5) (ρ – no data)	1	node missing in this case						
	2	955	/	27,7	/	/	/	/
	3	1046,7	/	45	/	/	/	/
Transposition (node 6) (ρ – no data)	1	node missing in this case						
	2	1773,7	/	51,44	/	/	/	/
	3	1889,3	/	81,24	/	/	/	/

2.2.5 Earth potential rise in case of short circuit at “Jug Nova” – Same as in section 2.2.4, data about the fault currents is given in Table 2.4, this time when fault occurs in the substation “Jug Nova”.

Table 2.4 - Data for injected current at “Jug Nova”, in case of three-phase and single-phase fault at “Jug Nova”

Start node	End node	Sub-transient		Transient		Steady	
		3-phase	1-phase	3-phase	1-phase	3-phase	1-phase
		Modulus [A]	Modulus [A]	Modulus [A]	Modulus [A]	Modulus [A]	Modulus [A]
Centralna		16994	18327	16711	18216	14992	17489
	Centralna	0	513	0	510	0	490
	SK-4	8497	5867	8356	8515	7496	8176
	SK-4	8497	5867	8356	8515	7496	8176
	TR 110/x kV	0	161	0	160	0	153
	TR 110/x kV	0	326	0	324	0	311
	TR 110/x kV	0	206	0	205	0	197

A third substation called „SK-4“, connected directly to „Jug Nova“, contributes to the total injected current fault in this case. The methodology by which the earth potential rise is calcultates is the same as in the previous section 2.2.4. As with the previous case, the results are shown in the same manner in Table 2.5.

As with the previous section, the same can be said for the case when fault occurs in the neighboring „Jug Nova“. Same as before, high values for the maximum touch voltage occur at „Jug Nova“, and pouring asphalt on the surface around the the substation would mitigate the issue.

Table 2.5 - Grounding voltage, touch voltage and step voltage that occur at different locations for single-phase fault at „Jug Nova“.

Observed location	**Case**	**Grounding voltage U_z [V]**	**Max. touch potential E_t [V]**	**Max. step potential E_s [V]**	**Surface not treated**		**Asphalt on surface: ρ_s=10000Ωm**	
					Max touch voltage U_t [V]	**Max step voltage U_s [V]**	**Max touch voltage U_t [V]**	**Max step voltage U_s [V]**
„Centralna“ (ρ=500Ωm)	1	594,6	178,92	58,87	102,24	14,72	11,18	0,97
	2	512,5	154,21	50,74	88,12	12,69	9,64	0,83
	3	574	172,72	58,83	98,70	14,21	10,79	0,93
„Jug Nova“ (ρ=287Ωm)	1	2892,4	867,7	289,2	652,4	125,7	54,23	4,74
	2	2786,9	836,1	278,7	628,6	121,2	52,26	4,57
	3	2856,6	859,6	282,8	646,3	123	53,72	4,64
Transposition (node 3) (ρ – no data)	1	node missing in this case						
	2	1081,7	/	31,37	/	/	/	/
	3	1167,1	/	50,19	/	/	/	/
Transposition (node 4) (ρ – no data)	1	node missing in this case						
	2	1887,5	/	54,74	/	/	/	/
	3	1976,8	/	85	/	/	/	/
Transposition (node 5) (ρ – no data)	1	node missing in this case						
	2	1021,6	/	29,63	/	/	/	/
	3	1173,3	/	50,45	/	/	/	/
Transposition (node 6) (ρ – no data)	1	node missing in this case						
	2	1855,9	/	53,82	/	/	/	/
	3	1976,5	/	84,99	/	/	/	/

3. CONCLUSION

The paper covered the process of designing a grounding solution for a new high-voltage substation in sub-optimal conditions. More precisely, because of the spatial constraints around the building of the substation, a conventional design could not be built. A detailed analysis was required, taking into account different scenarios and solutions for the grounding system.

After several iterations, the final ground grid design was achieved. Besides the design, it was concluded that several other measures should be taken in order to avoid any dangers during a fault at any one of the substations:

- The substation's old ground grid must be connected to the newly designed one, as well as to the building foundations and the cable row grounding;
- If during excavation it is discovered that the old ground grid is connected to the fence of the neighboring embassy, the connection must be severed in order to avoid very high touch and step voltages in the yard of the embassy;
- From the calculations it can be noted that the real problems concerning touch and step voltages occur in the neighboring substation „Jug Nova“. The reason behind this is the very low reduction factor of the power cables connecting the two substations, causing more than 90% of the fault current to be drained back into „Jug Nova“, as well as high earth potential rise along the power cables. In order to mitigate this, the points of transposition of the power cables need to be properly grounded;
- A layer of asphalt must be put on the surface around substation „Jug Nova“ in order to lower the touch and step voltages to acceptable limits;
- It is also advisable to do the same for substation „Centralna“ in order to avoid any potential risks.

Considering the above requirements, the designed grounding system should satisfy any requirements set by standards.

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