Analysis of the Grounding System of the Mines with Surface Exploitation

Nikolche Acevski [1], Mile Spirovski [2], Metodija Atanasovski [3] and Blagoj Stevanoski [4]

Abstract **– In the event of a single-phase short circuit on the 110 kV side of the switchgear "Oslomej", the power is distributed to all earth electrodes. During the above process, potentials significantly higher than the potential of the soil may occur on the metal parts of the mine equipment. The purpose of this paper is to perform an analysis of the 6 kV network in the mining power complex of "Oslomej", thereby calculating the parameters of the grounding system (touch and step voltages) by using empirical formulas and appropriate software.**

Keywords – **Grounding system (GS), touch and step voltages.**

I. Introduction

Thermal power plant Oslomej is complex technological and technical unity consist by mine with surface exploitation of minerals and thermal power plant along with object located in the area. Thermal power plant through 110 kV switchgear is connected with the HV transmition system of R. M, with three power lines, towards substation 110 kV – Kicevo, substation 110 kV – Vrutok, substation 110 kV Samokov. On the 110 kV switchgear is connected generator G1 with block transformer AT1 through wich is conected to power grid. Also in the thermal power plant are located transformer BT1 and transformer BT2, whose role is to supply the electricity consumption it the power plant, asynchronous motors, including coal mills, smoke ventilator, cooling water pump, power pump, fresh air ventilator, compressors etc. In the thermal power plant Oslomej is performed complex GS, set as grounding mesh that connects all electrical equipment in the plant, affecting the entire area inside the fence, with ancillary facilities. Mutually connected are grounding of elements in TPP Oslomej and parts of the switchyard 110kV plant in the TPP, 110kV power plant and conveyors for supply of coal from the mine to the plant storage. At first it is performed modeling of the GS network with equivalent schemes of the elements, then using the software package Neplan 5.2., the short circuit current injected into GS is calculated. Characteristics of the groundings are analyzed using the program Zazem.xls, MrezZaz.xls, while for calculating of the potentials and currents of GS, step and touch voltages, appropriate program developed with software package Matlab R2011a is used. In Section 2, the GS is described.

[1]Nikolche Acevski, is with the Faculty of Technical Sciences, 7000 Bitola, R. Macedonia, e_mail: nikola@acevski.com.

[2]Mile Spirovski, is with the Faculty of Technical Sciences, 7000 Bitola, R. Macedonia, e_mail: mile.spirovski@uklo.edu.mk.

[3]Metodija Atanasovski, is with the Faculty of Technical Sciences, 7000 Bitola, R. Macedonia.

[4]Blagoj Stevanoski, is with the Faculty of Technical Sciences, 7000 Bitola, R. Macedonia.

II. Grounding System

A. Modelling mesh grounding systems of substations

Substations 110 / 35 kV and 35/6 kV, Figs.1 and 2, are set grounding mesh that connects all electrical equipment inside the fence. The grounding resistance and potential differences of touch and step are calculated as in [1], [3], Tables I and II.

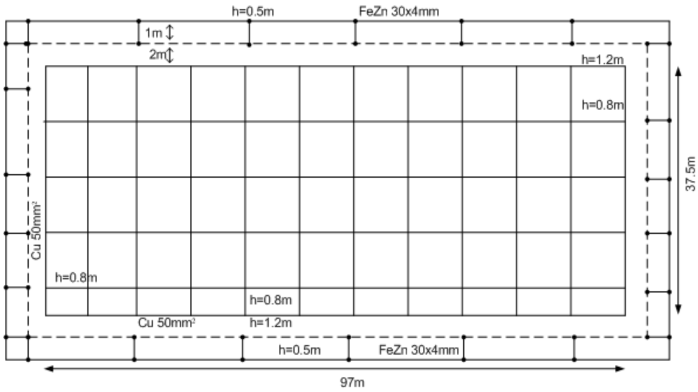


Fig.1. Mesh grounding of the substation 110/35 kV Oslomej

TABLE I
CALCULATION OF GROUNDING RESISTANCE, POTENTIAL DIFFERENCES OF TOUCH AND STEP IN PERCENT

According to:	*Rz* (Ω)	Δ*Ed* %	Δ*Ec* %
Zazem.xls	0,85	47,12	5,30
Nahman [1]	0,82	31,31	4,78

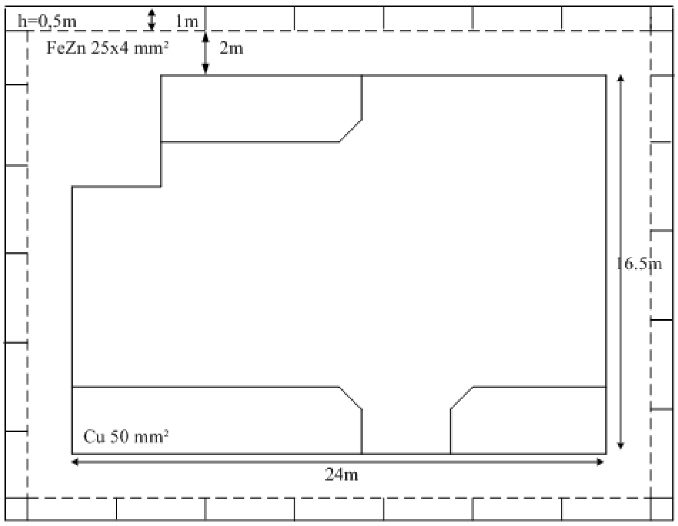


Fig.2. Mesh grounding of the substation 35/6 kV mine Oslomej

TABLE II
CALCULATION OF GROUNDING RESISTANCE, POTENTIAL DIFFERENCES OF TOUCH AND STEP IN PERCENT

According to:	*Rz* (Ω)	Δ*Ed* %	Δ*Ec* %
Zazem.xls	2,59	43,79	10,50
Nahman [1]	2,53	18,73	6,29

B. Modelling of TS 6/0,4 kV and auxiliary groundings

Each TS 6 / x kV will be modeled with transverse mounted active resistance to ground *R*, calculated by [3]. Auxiliary groundings of the various types of mining facilities and machines are modeled in an identical manner as the grounding TS 6 /x kV. It should be noted that cases are possible when more diverse plated grounding are connected to the same grounding spot. In that case, the replacement scheme GS will emerge as active resistors connected in parallel.

C. Modelling the surface grounding

If there are *rails and strips placed on the surface of the earth*, resistance to ground of the sliding bar or a length *l* and an equivalent diameter *d*, placed on the surface of the earth, with the average specific resistance of soil *ρ*, will be:

$$R = \frac{\rho}{\pi \cdot l} \ln \frac{2l}{d} \tag{1}$$

If the bar is on one end tied to the GS and thus is free of its other end, then it will be presented with a transversely mounted active resistance *R*. The picture we are given is a replacement scheme of the track when the two ends are connected to different plated grounding, Fig.3.

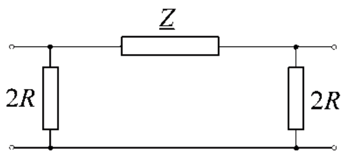


Fig. 3 - replacement scheme

The value of the parameter $\underline{Z}$ is calculated by the relation:

$$Z = \left[\frac{\rho_{Fe} \cdot l}{S} + 0{,}05\right] + j\left[0{,}1445 \log\left(\frac{2D_e}{d}\right) + 0{,}0157\mu_r\right] \tag{2}$$

ρ_{Fe} [Ω·mm^2/km] - specific resistance of iron
l [km] - the length of rail / bar;
S [mm^2] - cross section of rail / bar;
μ_r - relative magnetic permeability of the material;

$$D_e = 658\sqrt{\rho / f} \tag{3}$$

d [mm] - equivalent diameter of the bar / rail, with approximately valid $d = 1{,}128 \cdot \sqrt{S}$.

Excavators and other mining machinery and buildings that have large land area, with its caterpillars achieves good electrical contact with the ground. Thus, in case of short circuit in a 110 kV network, where they will get some potential, through the said contact lead the current in the ground and in their current environment creates a field that can be dangerous for people who are in their immediate nearby. For the purposes of modeling the equivalent scheme GS, they can be treated as concentrated grounding that the appropriate place of the equivalent scheme would introduce an active resistance *R*. Analyses show that the land surfaces of the excavators, machine with caterpillars and other devices that have contact with the ground surface, can be satisfactorily modeled by a suitable mesh GS, mounted horizontally on the ground of a certain small depth h. Moreover reticulated GS should have the same geometry as the geometry of land area of the dredge / device, and modeling can only be successfully performed if land surface is replaced by a dense network of horizontal strips, placed on a small distance between (the example *D* = 50 cm), buried in shallow (eg *h* = 5 cm).

D. Modelling 6 kV cables and characteristics of their models

6 kV cables EPN78 used for distribution of electricity in 6 kV input power network in the area of the mine, despite the power conductors (three phase conductors), have more and signal conductors or a conductive sheath. Signal conductors (i.e conducting sheath) are isolated in terms of land and phase conductors, and the emergence of single-phase short links in 110 kV network through them the transfer potentials in the GS of the mine. Thus, each cable, watched with its return route across the ground, may be presented with a I-replacement scheme, ie an ordinal impedance $Z = z{\cdot}l$. Thus, i.e longitudinal impedance per unit length in this case i will be calculated using known formulas Carson-'s, [1]:

$$\underline{z} = r + jx = \left(\frac{1000}{k \cdot s} + 0{,}05\right) + j \log \frac{D_e}{D_S} \tag{4}$$

k [Skm/mm^2] - conductivity specific material from which is made cable signals;
S [mm^2] - total cross section of signal cables;
De [m] - the equivalent depth of return current path across the ground (soil);
ρ [Ω · μ] - average value of the specific resistance of the terrain through which the cable passes;
Ds [m] - own middling geometric distance of the cable.
$D_S = \sqrt[3]{r_p \cdot (D/2)^2}$ - the signal cable has three conductors, placed in the vertices of an equilateral triangle with side *D* / 2.
r_p is the radius which is indicated by the conductor signal cable, and *D* is the outside diameter of the conducting sheath.

TABLE III
LONGITUDINAL PARAMETERS OF CABLES EPN78

	cable	*D*(mm)	*Ds*(mm)	*r*(Ωm)	*x*(Ωm)
1	EpN78 3x35+3x10	54	11,4	0,688	0,710
2	EpN78 3x50+3x16	60	13,2	0,679	0,700
3	EpN78 3x70+3x16	65	14,3	0,673	0,695
4	EpN78 3x95+3x25	67	15,5	0,669	0,690

E. Modelling of overhead lines with protective rope

Overhead lines also participate in transfer of currents and potentials in case of short circuit in the 110kV system, and because any such line should be represented in an appropriate manner so-called "- replacement scheme". Protective rope is of the type FeIII50mm^2, and a range of power lines lj = 300m.

Impedance of the protective rope for a span is calculated:

$$\overline{Z_{r1}} = \left(r_j + jx_j\right)\cdot l_j = (1{,}82 + j0{,}36)\Omega \qquad (5)$$

r_j, x_j -active and inductive resistance of the rope per km length

$$r_j = 0{,}05 + \rho_j \frac{10^3}{S_j} = 6{,}05\Omega / km \qquad (6)$$

$$x_j = 0{,}1445 \cdot \log\frac{2\cdot De}{d_j} + 0{,}016\cdot\mu_r = 1{,}22\Omega / km \qquad (7)$$

dj - diameter of the rope *Sj* = 50mm^2 *dj* = 0,009 m.

De - equivalent distance between the protective rope and phase conductors of power lines (m).

Rs - grounding resistance of each of the columns, which for 110 kV is the average power lines: *Rs*=10Ω. According to [1] the equivalent impedance of the grounding is:

$$\overline{Zek.v} = \sqrt{\overline{Zr_1}\cdot Rs} - \frac{\overline{Zr_1}}{2} = (2{,}97 + j1{,}61)\Omega \qquad (8)$$

Self impedance, mutual impedance between protective rope and phase conductors of power line and reduction factor are:

$$\underline{Z_{mi}} = 0{,}05 + j\cdot\log\frac{D_e}{D_m} = 0{,}05 + j2{,}24 \qquad (9)$$

$$\underline{Z_{si}} = r\cdot jx = 6{,}05 + j1{,}22 \qquad (10)$$

$$\underline{r} = 1 - \frac{\underline{Z_{mi}}}{\underline{Z_{si}}} = \frac{0{,}05 + j2{,}24}{6{,}05 + j1{,}22} = 0{,}9231 - j0{,}3542 \qquad (11)$$

III. SINGLE-PHASE CURRENT SHORT CIRCUIT AT 110 KV – MODEL IN NEPLAN

During the analysis of the GS, the problem with transfer potentials and protection from hazardous touch and step voltages, we take the single phase short circuit 110kV side of the plant switchyard as the most suitable for this kind of analysis. In case of single phase short circuit in switchgear 110/35/6 Elektrana, current is distributed to all GS as grounding of 110 kV poles, grounding of 110/35/6 Elektrana and GS of the mine. Using the software package NEPLAN 5.2.2 it is made electricity grid of MV of TPP Oslomej and it is estimated the value when single phase circuit happened on the 110 kV. Elements modeling is according to the standard models for the analysis of short-circuit, Figs.4 and 5, Table IV. For calculation of voltages in GS current value injected in the GS in case of a short circuit side is I_k'' = 11 017 A.

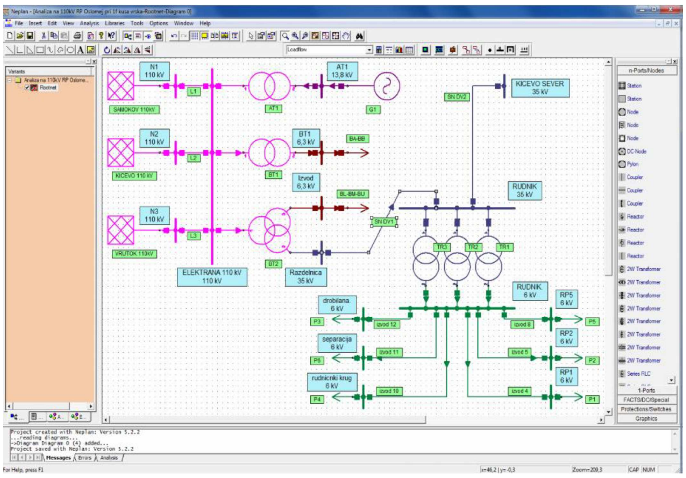
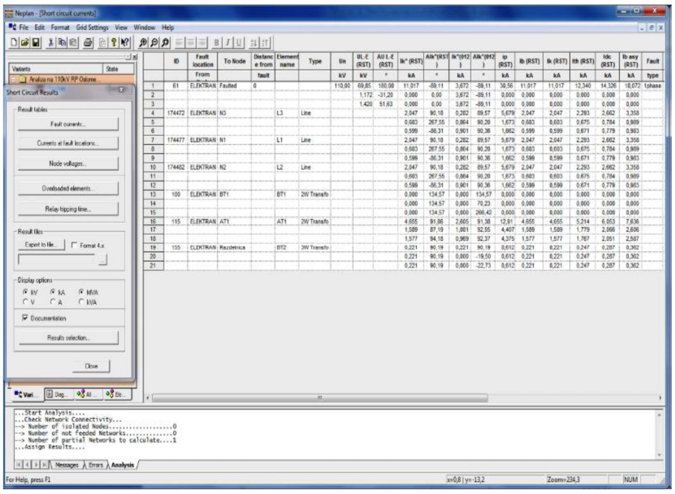


Fig. 4. Modeling the TPP Oslomej with NEPLAN

TABLE IV
CURRENT VALUE WHEN SINGLE-PHASE SHORT CIRCUIT HAPPENED ON 110 KV SIDE



	ID	Fault location From	To Node	Distance from fault	Element name	Type	Un kV	UL-E (RST) kV	AU L-E (RST) °	Ik" (RST) kA	AIk"(RST) °	Ik"(012) kA	AIk"(012) °	ip (RST) kA	Ib (RST) kA	Ik (RST) kA	Ith (RST) kA	Idc (RST) kA	Ib asy (RST) kA	Fault type
1	61	ELEKTRAN	Faulted	0			110,00	69,85	180,00	11,017	-89,11	3,672	-89,11	30,56	11,017	11,017	12,340	14,326	18,072	1phase
2								1,172	-31,20	0,000	0,00	3,672	-89,11	0,000	0,000	0,000	0,000	0,000	0,000	
3								1,420	51,63	0,000	0,00	3,672	-89,11	0,000	0,000	0,000	0,000	0,000	0,000	
4	174472	ELEKTRAN	N3		L3	Line				2,047	90,18	0,282	89,57	5,679	2,047	2,047	2,293	2,662	3,358	
5										0,603	267,55	0,864	90,20	1,673	0,603	0,603	0,675	0,784	0,989	
6										0,599	-86,31	0,901	90,36	1,662	0,599	0,599	0,671	0,779	0,983	
7	174477	ELEKTRAN	N1		L1	Line				2,047	90,18	0,282	89,57	5,679	2,047	2,047	2,293	2,662	3,358	
8										0,603	267,55	0,864	90,20	1,673	0,603	0,603	0,675	0,784	0,989	
9										0,599	-86,31	0,901	90,36	1,662	0,599	0,599	0,671	0,779	0,983	
10	174482	ELEKTRAN	N2		L2	Line				2,047	90,18	0,282	89,57	5,679	2,047	2,047	2,293	2,662	3,358	
11										0,603	267,55	0,864	90,20	1,673	0,603	0,603	0,675	0,784	0,989	
12										0,599	-86,31	0,901	90,36	1,662	0,599	0,599	0,671	0,779	0,983	
13	100	ELEKTRAN	BT1		BT1	2W Transfo				0,000	134,57	0,000	134,57	0,000	0,000	0,000	0,000	0,000	0,000	
14										0,000	134,57	0,000	70,23	0,000	0,000	0,000	0,000	0,000	0,000	
15										0,000	134,57	0,000	266,42	0,000	0,000	0,000	0,000	0,000	0,000	
16	115	ELEKTRAN	AT1		AT1	2W Transfo				4,655	91,86	2,605	91,38	12,91	4,655	4,655	5,214	6,053	7,636	
17										1,589	87,19	1,881	92,55	4,407	1,589	1,589	1,779	2,066	2,606	
18										1,577	94,18	0,969	92,37	4,375	1,577	1,577	1,767	2,051	2,587	
19	155	ELEKTRAN	Razdelnica		BT2	3W Transfo				0,221	90,19	0,221	90,19	0,612	0,221	0,221	0,247	0,287	0,362	
20										0,221	90,19	0,000	-19,50	0,612	0,221	0,221	0,247	0,287	0,362	
21										0,221	90,19	0,000	-22,73	0,612	0,221	0,221	0,247	0,287	0,362	

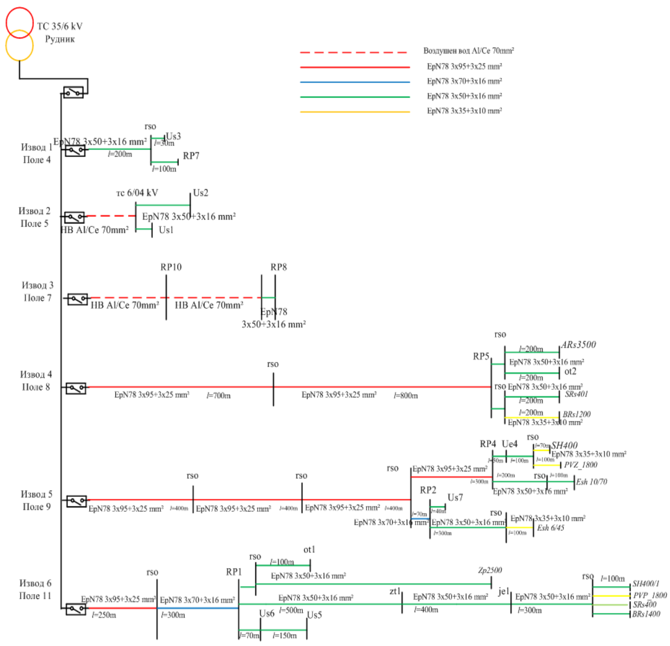


Fig. 5. Modeling the 6 kV network in the mine Oslomej

IV. Results

TABLE V
VOLTAGES AND CURRENTS IN THE GROUNDING SYSTEM

N	Grounding	*U*(V)	*Ed*(V)	*Ec*(V)	*Iz*(A)
1	RP110kV	1920,5	376,1	154,8	7435,9
2	TS35/6kV	382,8	167,6	40,2	247,8
3	RSO	321,4	82,7	28,9	30,9
4	US3	214,0	73,1	27,0	65,1
5	RP7	217,5	66,1	38,4	58,1
6	RSO	213,4	54,9	19,2	20,5
7	RP5	27,4	14,3	3,3	5,0
8	RSO	22,2	5,7	2,0	2,1
9	ARS3500	19,4	9,4	6,8	6,6
10	OT2	5,1	3,2	0,3	14,6
11	RSO	24,9	6,4	2,2	2,4
12	SRS401	21,2	8,2	3,1	9,3
13	BRS1200	18,9	9,0	2,3	12,4
14	ST2	22,9	13,8	1,4	46,7
15	RSO	97,7	25,1	8,8	9,4
16	RP4	27,0	14,1	3,3	4,9
17	UE4	20,9	11,5	1,8	24,4
18	RSO	15,8	4,1	1,4	1,5
19	SX400	14,7	5,5	4,9	3,7
20	PV31800	12,5	5,6	1,7	6,8
21	RSO	23,6	6,1	2,1	2,3
22	ES10/70	22,6	13,4	9,6	3,8
23	RP2	86,5	45,3	10,5	15,8
24	US7	81,9	45,1	7,0	95,2
25	RSO	78,7	20,3	7,1	7,6
26	ES6/45	76,7	47,0	14,3	12,9
27	RP1	83,7	43,8	10,1	15,3
28	RSO	70,2	18,1	6,3	6,7
29	OT1	47,0	29,5	2,5	134,1
30	ZP2500	53,7	25,9	18,8	18,2
31	ZT1	12,8	7,7	0,8	26,1
32	JE1	4,4	2,7	0,3	9,1
33	RSO	8,6	2,2	0,8	0,8
34	SX400/1	8,7	3,3	2,9	2,2
35	PVP1800	8,9	4,6	0,9	7,8
36	SRS400	8,8	3,7	1,3	3,8
37	BRS1400	8,9	4,3	1,0	5,9
38	US6	75,9	41,9	6,5	88,3
39	US5	67,6	37,3	5,8	78,6
40	TS110kV	274,0	68,5	6,9	601,8
41	TS110kV	274,0	68,5	6,9	601,8
42	TS110kV	274,0	68,5	6,9	601,8

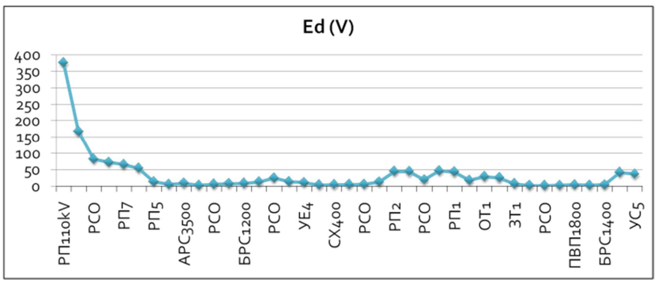


Fig.6. Touch voltages at the critical points in the network

In the Table V, voltages of the groundings, potential differences of touch and step and currents in the groundings are given, calculated by software Matlab R2011a. Critical points in the network are given by Figs. 6 and 7. According to calculations touch and step voltages, are in accordance with existing regulations [8], by which inside the plant are limited to 300V, during off $t = 0.1$sek, except in node 1, RP 110 kV. In this node, we should put vertical electrodes, or/and salt into the soil around the grounding to get better performances.

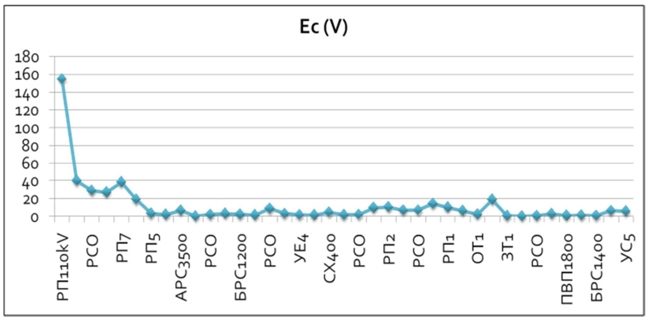


Fig.7. Step voltages at the critical points in the network

V. Conclusion

For analysis of the GS, the problem with transferred potentials and protection from hazardous touch and step voltages, we take the single phase short circuit on the 110kV side as the most suitable for this kind of analyses. At first it is performed modeling of the GS network with equivalent schemes of the elements, then using the software package Neplan 5.2. the short circuit current injected into GS is calculated. Characteristics of the groundings are analyzed using the program Zazem.xls, MrezZaz.xls., while for calculating of the potentials of GS, currents in the branches of the GS, step and touch voltages is used appropriate program developed with software package Matlab R2011a. The results obtained with calculations can be used in determining the risk of excessive voltages and critical points in the network and according to the results can be propose appropriate technical solutions for proper protection and proper building of the GS.

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