Assessment of the Safety Conditions from High Touch and Step Voltages in the Grounding Systems of the mines

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Abstract: **In this paper are described and elaborated mathematic models which are applied for solution of problem with transfer of potential in the mines. Appropriate algorithm is made as programmed package which is used for analysis or better says, for anticipation of the conduct of al grounding system (GS) in the area of the mine REK Bitola (Suvodol) when faults to ground appeared in the system 110 kV for present situation (after July 2007), with new 400 kV TL Bitola 2-Amindeo (Greece).**

Keywords: **groundings, transferred potentials, safety conditions, touch and step voltages**

I. Introduction

Because of the nearness of the sources of REK Bitola as well as because of the meaning of the mine "Suvodol" problem of transferred potentials is especially expressed. Cables in the network are with rubber isolation that contains three-phase conductors as well as additional signal conductors made by cooper with relative big section. So all objects in part of the mine (operative stations, diggers, transport tapes, engines and the other consumers on medium (MV) and low voltage (LV)) are mutual galvanic harnessed and together with their groundings, they formed GS of the mine. At appearance of fault to ground at station 110/6 kV/kV of the mine or the network 110 kV in nearness of the mine, that power is distributed at all GS (tower groundings on 110 kV transmission lines (TL), grounding on substation 110/6 kV/kV and groundings by individual MV consumers). The problem with transfer of potentials also is expressed with the systems for transport of soil and chats, as and substation TS MV/LV by 6 kV network in mine, where groundings of that TS are sources of current field and dangerous voltage of touch and step.

II. Grounding System - Model

Netlike Grounding - Model

Small part of the current (just 9,4 %) that is injected in GS of the mine will go to the earth over netlike grounding of TS 110/6kV/kV "Suvodol". For this calculation we will use simplified way the entirely netlike grounding will be modelled with one horizontal panel which equivalent diameter has the same parameter *A* as the netlike grounding itself. For calculation of the resistance the expression [5] is used where is ρ =100 Ω*m*:

$$D_{ek} = \sqrt{4 \cdot A / \pi} = 1{,}128 \cdot \sqrt{A}\,, \qquad (1)$$

$$R_{TS} = \frac{\rho}{2 \cdot D_{ek}} = 0{,}725\Omega\,, \qquad (2)$$

Modelling of Transmission Lines

When TL is performance with protective rope; it participates of the transfer of the currents and potentials when fault to ground appeared in the system 110kV. Therefore, in replacement scheme in the network of GS every TL ought to be presented on the same way, with so-called "π-scheme" [5]. In power network of the mine "Suvodol" exist only one TL provided with protective rope. That is TL 110kV TS 110/6 "Suvodol"-TS 400/110 Bitola2", who is consecution like two systematic (with two independent threat on phase conductors with length l=2,7 km, 2x3xA1/C240/40mm²), type of protective rope Fe III 50mm². According to [5], for impedance per kilometre length of protective rope we can get:

$$\underline{z} = \left(0{,}05 + \frac{1000\rho_{Fe}}{S_{Fe}}\right) + j\left(\log\frac{2D_e}{d} + 0{,}0157\mu_r\right) \qquad (3)$$

$$\underline{z} = (4{,}24 + j1{,}24)\Omega / km$$

With D_e is indicated equivalent depth of the return path of current in the earth, which is according to Carson model depend of ρ and frequency *f*:

$$D_e = 658\sqrt{\rho / f} = 930{,}6m \qquad (4)$$

As we know number of aperture 12, for average a=225 m than for impedance of average aperture we have

$$\underline{Z}_r = a \cdot \underline{z} = (0{,}954 + j0{,}279)\Omega / aperture\,, \qquad (5)$$

TL with more than 10 apertures is treated like infinite TL, without making any important mistake in modelling. TL may be equivalent with it entering impedance:

$$\underline{Z}_{VL} = \sqrt{R_{ST} \cdot \underline{Z}_r} - 0{,}5 \cdot \underline{Z}_r = (2{,}04 + j0{,}22), \qquad (6)$$

Where $R_{st} = 6{,}5\Omega$ is average value of grounding resistance on the separates towers of TL.

Modelling of Cables 6 kV

Every cable looked together with returned path through earth, can be presented with I-removal scheme, i.e. with one ordinal impedance $\underline{Z}=\underline{z}\cdot l$. Longitudinal impedance that is impedance of unit length $\underline{z}$ will be [5]:

$$\underline{z} = r + jx = \left(\frac{1000}{\kappa \cdot S} + 0{,}05\right) + j\log\frac{D_e}{D_s}\,, \qquad (7)$$

Modelling of Groundings on TS 6/X kV/kV and Accessory Groundings

Each TS 6/x kV/kV which has own grounding with known grounding resistance *R*, in removal scheme of GS will be node, so-called "grounding place", and will be modelled with

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cross located active resistance R. Accessory groundings of different types of mine objects and machines are modelling of identical way like groundings of substation TS 6/x kV/kV. We can say that it happens that more grounding are galvanic connected in one grounding place. In that case, in removal scheme will appear as parallel connected active resistance as there are different galvanic connected groundings.

Surface Groundings –Model

According to [7], R of transporters/tracks with length l and equivalent diameter d on the surface of earth is:

$$R = \frac{\rho}{\pi \cdot l} \cdot \ln \frac{2l}{d}, \tag{8}$$

According, to this, if the track is located on the area of earth and if it is linked on one end with GS and it is free on the other sight, than it can be treated like elementary grounding, that in equivalent scheme GS on individual grounding place will entered active resistance R. As both ends of track are galvanic connected for different grounding places, then in removal scheme of GS the track will have to introduce with π-scheme, Fig.1.

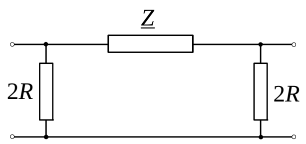

Fig. 1.π–removal scheme for transporters/track

Parameter $\underline{Z}$ of ordinal branch in π– scheme is [7]:

$$\underline{Z}=[\rho_{Fe}\, l/S + 0{,}05]+j\cdot[0{,}1445\cdot\log(2D_e/d)+0{,}0157\cdot\mu_r], \tag{9}$$

Analyses shows that step upon areas of diggers, transporters and other equipment (which with their caterpillars realize good power contact with earth), satisfactory can be modelled with individual netlike GS, horizontally placed in earth on certain small depth h. Thereat, netlike GS will need to have the same geometry like geometry of step upon area of digger/machine, and own modelling itself can be successfully done if step upon area is changed with heavy network on horizontal tracks, placed on small distance from one another (e.g. D=50 sm.), buried in small depth (e.g. h=5 sm).

III. ESTIMATION-CURRENTS AND POTENTIALS

When one-phase fault to ground appear in 110 kV patch board of mine “Suvodol” that is of arbitrarily place of TL 110 kV TS 110/6 “Suvodol”-TS 400/110 “Bitola 2”, comes to flux of currents per grounding of station, and the potential of grounding, V_Z. The analyses show that most unfavourable case, from aspect of the quantity of potential of grounding, is for one-phase fault to ground produced in the station. The whole current of fault doesn’t go into the earth, but just one part of it, which will be indicated with I_Z. This current in different ways, flows through earth to source of current, i.e. to station 400/110 “Bitola 2”. If with $\underline{Z}_Z$ we indicate complex “enter impedance of the whole GS at station 110/6 than:

$$V_z = Z_z \cdot I_z, \tag{10}$$

In the paper it is supposed that current on fault to ground is known, produced in TS 110/6 “Suvodol”. Data for value of the current of one-phase fault to ground in power system of R.M. are received from competent offices. The current I_z =21976 A that is injected in GS in mine is calculated like in [5]. After that, by known (calculate or measured) value of entered impedance, we can calculate the potential V_z =1538 V in netlike grounding, node SO.

After determination of potential V_Z on the place of fault, we can determine potentials and for other groundings in the region of the mine. In the algorithm according to which is produced the programmed package Suvodol, is used matrix approach for solution of the problem of distributing of currents and transfer of potentials in GS in the mine. Solution of mentioned problem is done with help of matrix of impedances, [Z], of GS. For this purpose, primary, according to known plot of feeder 6kV and their known parameters, is generated so-called matrix of admittances [Y] of GS.

$$[Z]= [Y]^{-1} \tag{11}$$

Then, potentials $\underline{V}$(i=1,N), of the separate groundings are:

$$V_i = Z_{is}\cdot I_Z \; ; \; i = 1,2, ..,N, \tag{12}$$

IV. RESULTS OF THE ESTIMATION AND MEASURES FOR ELIMINATING DANGERS

Whole network 6 kV is divided, on:

Coal system (SJ);	First system (S1);
Second system (S2)	Zero system (S0).

That is made, so we can see what is the stake of each of the systems of the mine in drop off of total current I_Z although it’s partial GS are galvanic connected in the (node “SO”) through it’s grounding CENTRAL, TAB. I. When we evaluate the attained results, if estimated voltages of touch and step are in the permitted borders, we need to respect:

1. Time of duration of one-phase fault to ground, T.
2. Allowed voltages of touch and step, depending on T.

According to the results from the studies [1], [2], time of disconnection of fault to ground made in the station 110kV of mine is t=0,1 s. According to [5], for that time allowed voltage of touch/step, is 300 V.

From the received results, we can see that maximum voltages of steps are regular for 40-60 % smaller than maximum voltages of touch. In TAB. II are present 6 nodes of 6 kV network that have maximum potential difference of touch that exceeds 300V. Solution can be done with:

1. Installation of additional ring around the object, 1m of its margins and at depth of 0,8m.
2. Asphalting the path around with width of 1m.

Here is analyzed the first method, which is cheaper. For that reason grounding type PRP (fig. 2) that is consisted of one rectangular ring with sizes 3,5x1,4 m buried in depth h_1 = 0,5 m and two vertical plug F2" that are 3 m long, we will add another ring with dimensions 5,5x3,4 m, buried in depth h_2 = 0,8 m and we will have new grounding called PRP2 (fig. 3).

Characteristics of this new type of grounding are explored in program package “ZAZEM” and it is concluded that the biggest potential differences of touch and step are by the length in direction of 0-A (fig. 4).

TABLE I DISTRIBUTION OF INJECTED CURRENTS AND EQUIVALENT IMPEDANCES PER SEPARATED SYSTEMS OF THE MINE FOR TOTAL INJECTED CURRENT I_z =1000A

	S i s t e m	I_r	I_x	I			Z
/	/	(A)	(A)	(A)	(o)	%	
1	Coal (SJ)	277.62	-19.71	278.32	-4.06	26.7	0.25376
2	First (S1)	217.72	-50.86	223.58	-13.15	21.5	0.31589
3	Second (S2)	151.09	-16.38	151.98	-6.19	14.6	0.46472
4	Zero (S0)	255.55	-1.06	255.55	-0.24	24.5	0.27637
5	Netlike grounding	70.64	67.11	97.44	43.53	9.4	0.72481
6	110 kV TL	27.37	20.89	34.43	37.35	3.3	2.05105
	Total	1000.00	0.00	1000.00	0.00	100.0	0.07063

TABLE II. NODES IN NETWORK 6 KV IN WHICH $E_D > 300$ V

	System	node	Grounding type	m	U (V)	E_c (V)	E_d (V)	U_d (V)
1	(SJ)	RP78	RP78	40	1113.0	160.8	374.7	353.2
2	(SJ)	DOM.TRAFO	RP16	100	1478.7	265.9	386.0	334.3
3	(S2)	TS4	RP16	100	1499.0	269.7	391.0	338.0
4	(S2)	ES10	BG_JL3	40	706.0	348.2	374.7	353.2
5	(S0)	RP910	RP78	40	1143.0	159.5	372.2	350.7
6	(S0)	PRP	PRP	100	1035.5	249.0	487.4	421.6

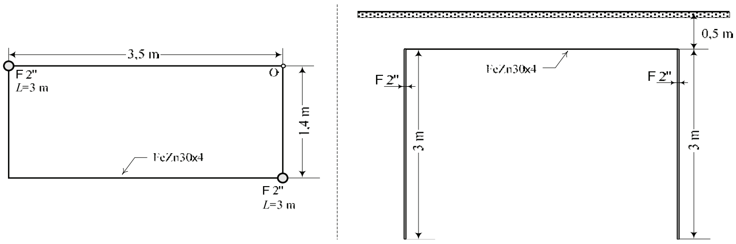

Fig.2. Grounding type PRP

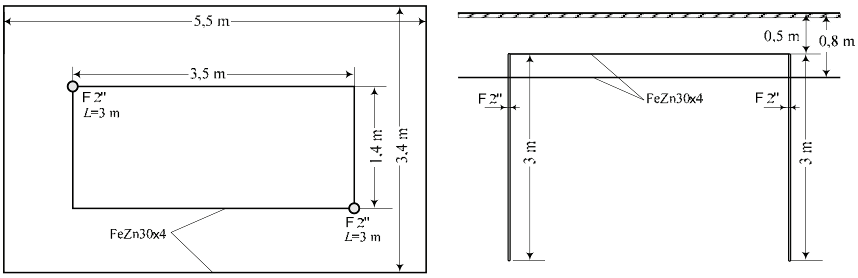

Fig. 3. New grounding type PRP 2

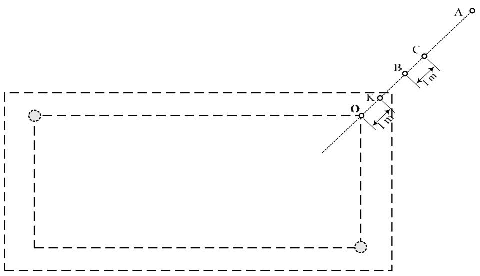

Fig 4. Estimation of potentials in the surface of earth

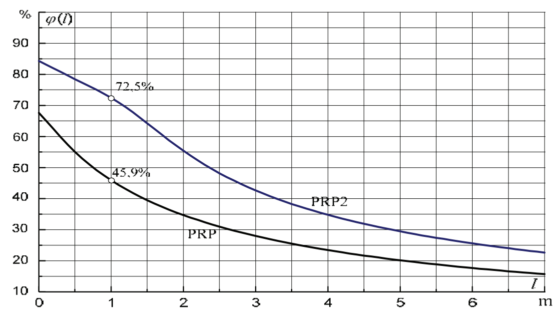

Fig.5. Distribution of potentials per length of critical direction

On the fig. 5. φ_K ($\varphi_K = \varphi_{min}$) in the critical item k, that is located 1m from the edge of object, and the lowest when ΔE_d is difference between potential φ_0 of the object and φ_K, in item k. Maximum potential difference of touch:

ΔE_d = 54,1% for permanent grounding type PRP

ΔE_d = 27,5% for new grounding type PRP2.

So, after putting second contour, we obtain new, grounding type PRP2, at which maximum voltage of touch will be reduced of the value ΔU_d = 169 V. Calculations show that the biggest potential difference of step is again in direction 0-A, between the points B and C which are alienated 1m.

TABLE III. CHARACTERISTICS OF GROUNDINGS

Grounding type	R_Z , ( )	E_c (%)	E_d (%)
PRP	11.35	21.7	54.1
PRP2	8.05	17.2	27.5
RP16	7.82	16.8	24.3
RP16mo	5.56	13.9	20.1

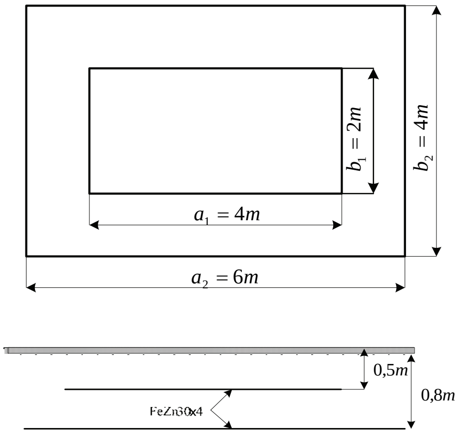

Fig. 6. Grounding type RP 16

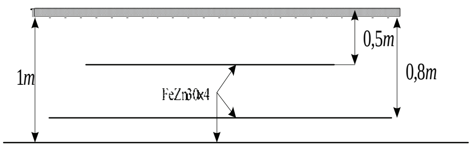

Fig.7. New grounding type RP16 mod

Grounding type RP16 is consisted of two rectangular rings Fe Zn 30x4, on depth h_1 = 0,5 m, h_2 = 0,8 m, fig. 6. New grounding type RP16 mod is consisted of three rectangular rings Fe Zn 30x4, on depth h_1 = 0,5 m, h_2 = 0,8 m, and h_3 = 1 m fig. 7. In this case touch voltages are: DOM TRAFO-(ΔU_d = 276.2 V) and TS4-(ΔU_d =279.3V).

Grounding type RP78 is consisted of three rectangular contours with 8 vertical elements, fig.8.

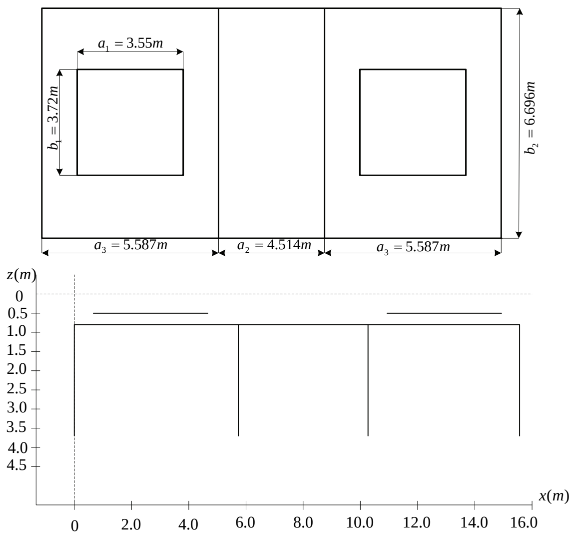

Fig. 8. Grounding type RP 78

After putting additional contour, we obtain new, grounding type RP78 mod, at which maximum voltage of touch will be reduced of the value ΔU_d = 188.5 V.

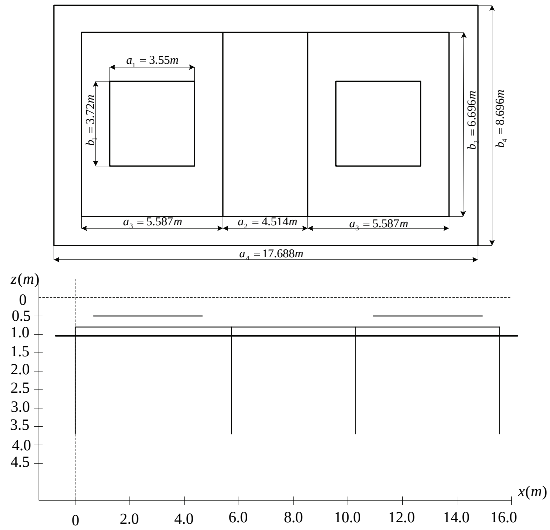

Fig.9. New grounding type RP78 mod

Grounding type BG_JL3, in the second system in node ES10 is in fact digger. So, measures in this case should be salting the path around with concentration of 0.5-1 % salt, or putting around the soil with big specific conductivity.

V. CONCLUSION

1. The biggest danger of transferred potentials in 110kV network in region of mine “Suvodol” at REK –Bitola is when fault to ground appear in TS 110/6kV/kV.
2. The highest potentials in MV network of mine are those in so-called maximum regime, when all power sources are on.
3. Time of disconnection for the current that is produced is estimated that is t = 0,1s. For this time is suggested that as criteria of dangerous to be accepted $U_{d.doz}$= $U_{c.do}$ =300V.
4. For these adopted criteria for safety is obtained that real danger of higher voltage of touch is noticed in 6 nodes.
5. Groundings in these TS 6/0,4 kV should be improved with adding one rectangular ring around the objects. Alternative, whole zone around the objects should be asphalted.

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