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

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Abstract - **In this paper, beside the results of calculation, are described and elaborated mathematic models which are applied for solution of problem with transfer of potential. 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 when faults to ground appeared in the system 110 kV for the present situation.**

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). For mutual galvanic connection of groundings from supplied objects at 6 kV networks, at appearance of fault to ground in 110 kV network, by metal pieces of equipment may occur potentials appreciably higher of potential by ambient soil. 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".

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Accuracy of the final results of the analysis for the potentials of GS of the mine is little connected with the accuracy of the calculated R_{ts} of the netlike grounding.

For this calculation we will use simplified way the entirely netlike grounding will be modeled with one horizontal panel which equivalent diameter has the same parameter *A* as the netlike grounding itself.

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

For calculation of the resistance we will use the following expression [8], where is $\rho = 100\Omega m$:

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

Modeling 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" [8]. 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 [8], for impedance per kilometer length of protective rope we can get:

$$\underline{z} = \left(0{,}05 + \frac{1000\rho_{Fe}}{S_{Fe}}\right) + j\left(\log\frac{2D_e}{d} + 0{,}0157\mu_r\right) \tag{3}$$
$$\underline{z} = (4{,}24 + j1{,}24)\Omega/km$$

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*:

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

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

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

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

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

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

Modeling of Cables 6 kV and Characteristics of their Models

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 [8]:

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

Modeling of Groundings on TS 6/X kV/kV

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 the grounding itself in removal scheme will be modeled with cross located active resistance *R*.

Accessory Groundings – Model

Accessory groundings of different types of mine objects and machines are modeling 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 of GS will appear, as parallel connected active resistance as there are different galvanic connected groundings.

Surface Groundings –Model

According to [9] grounding resistance of transporters/tracks with length *l* and equivalent diameter *d* on the surface of earth at average ρ is:

$$R = \frac{\rho}{\pi \cdot l} \cdot \ln\frac{2l}{d} \qquad (8)$$

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.

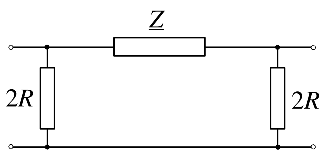

Fig. 1. π–removal scheme for transporters/track

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

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

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 modeled 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 modeling 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 of Currents and Potentials in Grounding System

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 unfavorable 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:

$$V_z = Z_z \cdot I_z \qquad (10)$$

The value of the equivalent impedance Z_z of whole GS needed for estimation of potential V_z may be received in two ways: with direct measuring or with estimation. In this paper it is calculated with computer programmed based on the method of independent voltages.

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=17196 A that is injected in GS in mine is calculated like in [6]. After according current I_z is estimated by known (calculate or measured) value of entered impedance $Z_z = Z_{ek}$, calculate the potential V_z=1215 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. It's very useful, particularly when the calculations are made by computer, if there are used matrix methods. 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 [11]. 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, [11]. With its inversion [*Z*]:

$$[Z] = [Y]^{-1} \qquad (11)$$

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

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

With $Z_{is}\,(i = 1, N)$ are elements in the column "*s*" of matrix [*Z*], hereby, with "*s*" is indicated the index of node that is referred to grounding.

IV. RESULTS OF THE ESTIMATION AND MEASURES FOR ELIMINATING DANGERS

Whole network 6 kV is divided, on:

1. Coal system (SJ);
2. First system (S1);
3. Second system (S2) and
4. Zero system (S0).

Table 1 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	φ		Z
/	/	(A)	(A)	(A)	(o)	%	Ω
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 2. Nodes in network 6 kV in which $\Delta E_d > 200$ V

	System	node	Grounding type	ρ (Ωm)	U (V)	ΔE_c (V)	ΔE_d (V)	ΔU_d (V)
1	(SJ)	RP6	RP16	40	770	139	201	189
2	(SJ)	RP78	RP78	40	908	127	296	279
3	(SJ)	DOM.TRAFO	RP16	100	1168	210	305	264
4	(S2)	TS4	RP16	100	1184	213	309	267
5	(S2)	RP5	RP16	50	778	140	203	188
6	(S2)	ES10	BG_JL3	40	558	275	296	279
7	(S0)	RP910	RP78	40	903	126	294	277
8	(S0)	PRP	PRP	100	814	197	385	333

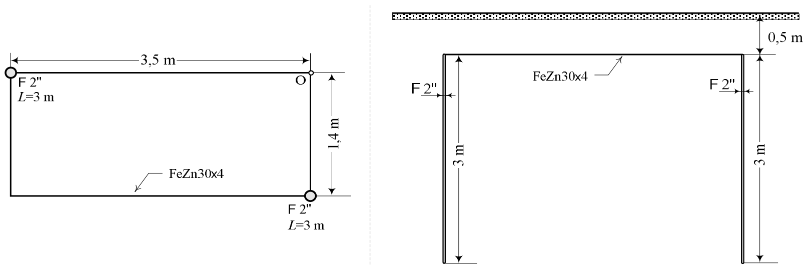

Fig. 2. Grounding type PRP

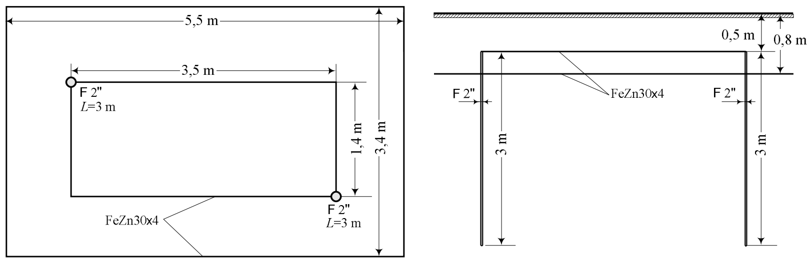

Fig. 3. New grounding type PRP 2

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 central separation (node "SO") through it's grounding type "CENTRAL", and they are treated like that in the estimations as well. The results are shown in table 1. When we evaluate the attained results, if estimated voltages of touch and step are in the permitted borders, we need to respect time of duration of one-phase fault to ground and allowed voltages of touch and step.

According to the results from the studies [1], [2], time of disconnection of fault to ground made in the station 110kV is t=0,1 s. In the European and American standard (ANSI/IEEE Std80-1986) the lowest values are when person is in contact with metal areas, and voltage of touch for man with 70 kg is:

$$\Delta U_{ddoz} = \Delta U_{cdoz} = 157/\sqrt{t} \qquad (13)$$

According to [5] if the time of disconnection is t=0,1s, allowed voltage is 300 V. From this point we can make the conclusion that if time of disconnection of fault to ground produced in 110 kV network is 0,1 s, 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, so we can conclude that dangers in 6 kV network in mine when fault to ground appear in 110 kV system are voltages of touch. In table 2 are present nodes of network that have maximum potential difference of touch that exceeds the value of 200V. In it there are shown voltages of nodes U(V), ρ (Ωm) as well as the voltages of touch ΔU_d and potential difference of touch ΔE_d. But if the measure for danger is ($\Delta U_{d.doz} = \Delta U_{\sim.doz} = 300$ V), then in 6 kV network in the mine danger of more higher voltage of touch will appear one in the knot PRP in zero system (ΔU_d = 333 V). Solution of this problem can be done in more than one way but the simplest are the following:

1. Installation of additional ring around the object, 1m of its margins and at depth of 0,8 m.
2. Asphalting 1 m path around the object with thickness 5sm.

Asphalting will occur if there isn't objective limitation for installation of the additional ring around the object itself. For that reason permanent grounding type PRP (figure 2) that is consisted of just one rectangular ring with sizes axb=3,5x1,4m buried in depth h_1 = 0,5 m and two vertical plug F2" that are 3 m long, we will add another rectangular ring with dimensions a2xb2=5,5x3,4m, buried in depth h_2 = 0,8 m and this way we will have new grounding that will be called type PRP2 (fig. 3). Characteristics of this new type of grounding are explored in ZAZEM and it is concluded that the biggest potential differences of touch and step are by the length, direction of 0-A.

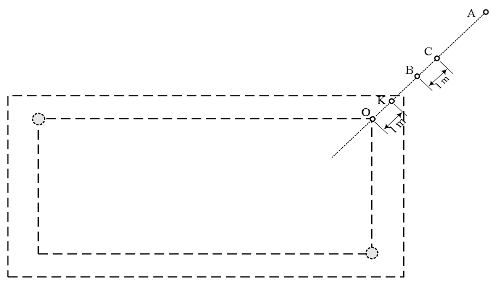

Fig. 4. Estimation of potentials in the surface of earth

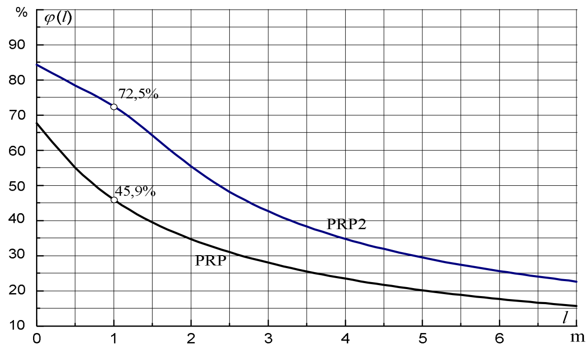

Fig. 5. Distribution of potentials per length of critical direction

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 the potential difference of touch ΔE_d is difference between potential φ_0 of the object and φ_K, in item k:

$$\Delta E_d = \varphi_0 - \varphi_K \qquad (14)$$

So, after putting second, additional, contour, we obtain new, grounding type PRP2, at which maximum voltage of touch will be reduced of the value ΔU_d = 169 V. Besides these analyses, there are calculated potentials differences of step ΔEc. Calculations show that the biggest potential difference of step is again in direction 0-A, between the points B and C which are 1m from one to another. Essential characteristics of groundings type PRP and PRP2 are shown in table 3.

Table 3. Characteristics of groundings type PRP and PRP2

Grounding type	R_Z, (Ω)	ΔE_c (%)	ΔE_d (%)
PRP	11,35	21,7	54,1
PRP2	8,05	17,2	27,5

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. Time of disconnection for the current that is produced is estimated t = 0,1s. For this time is suggested that as a criteria of danger should be accepted $\Delta U_{d.doz} = \Delta U_{c.doz}$ = 300 V.
3. For this adopted criteria for safety is obtained that real danger of higher voltage of touch is noticed only with one grounding, in the node PRP (ΔU_d = 333 V).
4. It is suggested the grounding in this TS 6/0,4 kV to be improved with adding one rectangular contour. Alternative, whole zone around the object should be asphalted with width of 1m and thickness 5 sm.
5. Currents of fault to ground after building of 400kV relation Bitola2-Amindeo, will be bigger at least for 40-60%. That will provoke enlargement of dangers from transferred potentials in MV network of the mine for approximately the same % and appearance of new dangerous places in MV network, table 2.

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