USABILITY OF MINING MACHINERY TO IMPROVE EFFICIENCY OF AN ELECTRIC SHOCK PROTECTION IN MV POWER NETWORK

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Abstract: - In the paper the investigated results of construction resistance to ground of mining machines under earth-fault conditions in MV power network are presented and discussed. On the basis of the results the conclusions concerning usability of an excavator-transporter-dumping conveyor system (ETDc) as natural additional earthing. arrangement are formulated

Key-Words: - electric shock protection, power network, mining machine.

1 Introduction

Earth-faults produce usually a direct hazard of an electric shock for servicing personnel at any MV power network application. This problem is of particular importance for surface minings where, both structure and configuration of the power feeders must follow the working face. Considerable number of machines and electrical equipment located over a relatively small area significantly increases probability of the accidental earthing due to mostly mechanical failures of suppying trailing cables [1]. The electric energy is provided via movable transformer and/or distribution substations where the electric shock protection is ensured by earthing conductors (PE) permanently connected to a central grounding system of the stationary MV substations. It is coordinated with earth-fault protections [2]. However, due to high probability of the PE conductors failure and lack of effective on-line measuring systems of electrical continuity of the PE conductors the movable substations are required to be equpped additionaly with independent, auxiliary local earthing arrangement. Usually it is realized by means of the earth pipe or rod. Execution of the effective local earth electrode in practice is not easy and cause difficulties under its removal as well. Therefore, seeking for another equivalent solutions is technically and economically justified. It can be realized for example by additional electrical flexible connection with the central grounding system of the second MV stationary substation, if double supplied, or with effectively grounded electrical and/or mechanical equipment like water-works pumps, pipes of the mine drainage etc. Sometimes, it is connected to steel supporting structures of the large mining machines particularly to ETDc systems using their constriction resistance to ground as the natural earth electrode embeded in foundation. However, according requlations it can not be accepted as the additional independent local earthing arrangement since, its efficiency can be varried from fault to fault and can be environment conditions dependent as well.

In the paper investigated results of the structure resistance to ground of the selected machines used in brown coal surface mines are presented and discussed. The investigations were carried out for different weather conditions under 1-phase short circuits to ground in 6 kV networks operating both with isolated neutral and/or with neutral earthed through coil and through a low ohmic resistor (45-75 Ω). Therefore, different earth current values as well as different potential distribution in the ground were searched. On the basis of the results the conclusions concerning applicability of the selected mining machine constructions (particulary ETDc system) are formulated and some solutions of such the effective shock protection system are recommended.

2 Construction resistance to ground of mining machines and equipment

Most of the mining machinery and electrical power equipment in strip mines is adapted for permanent and/or frequent relocation under operation. Some of them possess an independent drive with caterpillar running system (like: wheel excavators, dumping conveyors, driving stations of belt conveyors) while, the others are located on pontoons or sliding skids (like movable distribution substations, belt conveyor flights etc). The electric shock protecion is performed by electrical connection (by means of the earthing PE conductor) with the control grounding system of the stationary transformer substation. As the case may be, it is connected also with grounding systems of another mating machines or equipment as it is illustrated in Fig 1.

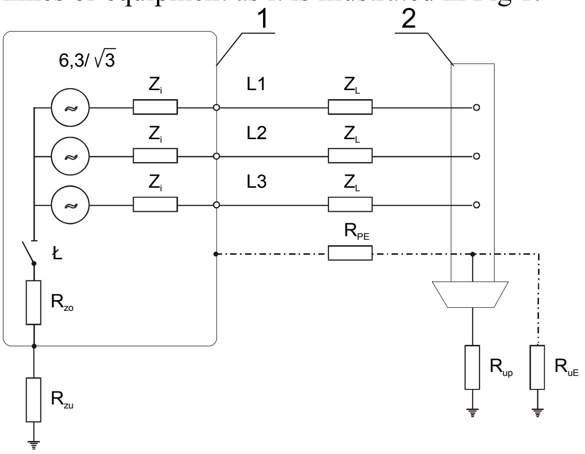

Fig 1. Circuit diagram of the electric shock protection. 1-stationary supplying substation, 2-movable machine or electric equipment, Z_i Z_L - impedance of transformer and power conductor, R_{ZO}, R_{ZU}- resistance of neutral point and grounding system of the main substation, R_{PE}, R_{up}, R_{UE} – resistance of the PE conductor, construction to ground and another equipment or auxiliary local earthing arrangement respectively.

Therefore, under the PE conductor failure ($R_{PE} \rightarrow \infty$) and particularly for lack of connection with another earthing arrangement ($R_{UE} \rightarrow \infty$) the construction resistance to ground of the movable machine or substation (R_{up}) is strongly related to geophysical properties of superficial layer of the ground, butting face of the equpment to ground and to value of its force of inertia. Of course, weather conditions are of great importance as well. In polish strip mines of a brown coal three characteristic kinds of the ground can be distinguished:

- overlay virgin soil, mostly seat clay (at upper layers of an excavation) passing to sandy soil with a high amount of a bank-run gravel of a different compactness and humidity (at the bottom)
- made ground which is a mixture of different kind of soil removed from a various areas of the strip mine and usually mixed with an ash from electric power station. It is almost homogeneous however, its compactness is poor.
- visible brown coal field of a high compactness. its moisture content is relatively low and depends on efficiency of the mine drainage.

The investigations carried out for all polish strip mines of a brown coal under different weather conditions (for all seasons) have indicated the lowest value of electrical resistivity ρ (about over a dozen or so Ωms) for virgin soils (seat clay) which are able to keep a high moisture content for a relatively long time. However, with the increase of the sand amount their resistivity was increased up to about 150 Ωm. The highest resistivity (from 200 Ωm up to over 2500 Ωm) indicate sandy, loose and dry soils while, its of the visible coal fields as well as the compacted earth (dumped) is small and does not exceed 35 Ωm and 50 Ωm respectively. It is important to underline that the resistivity is decreased tremendously with a „territorial development" (amount of metallic elements inside the ground). Therefore, for such the areas the „foundation" resitance of the machines was the smallest provided that the „constriction" resistance (between metallic construction and ground) was relatively low. The constriction resistance is a main part of the foundation resistance (R_{up} – see fig 1) and its value decreases with the increased number of the real contact points with ground. Thus, for the large mining machines with independent driving system the measured foundation resitance was found to be about 1 Ω what is 2-times lower with compare to these of the smaller overall dimensions and weight. However, for these located on pontoons and/or sliding skids it was much higher, although the pontoons seem to be more effective due to more stable contact conditions with the ground (limited moisture evaporation). Their foundation resistance, when located on an undisturbed soil and/or on a brown coal bed was ranged between 1.5 Ω and 19 Ω. However, for the made ground it was increased tremendously even over 500 Ω, particularly for the newly estabilished, equimpent. The resistance of the machine construction to ground (foundation) was measured also before and after 1-phase short-circuits in MV network to check its variation under earth-fault conditions. For the relatively high currents over 30 A rms and lasting for more than 5 s the foundation resistance was found to be increased under following faults to earth respectively (e.g 0.9 Ω; 1.4 Ω; 2 Ω; up to about 40 Ω for driving station of belt conveyor). Such the high value of the resistance can be kept for a long time particularly if the machine is not moved. However, it is a very seldom case since, the high current ground faults are switched off almost immediately. Especial attention was paid on the belt conveyors due to real possibility for their application as the effective independent earth electrode. Two types of the conveyors are usually used in strip mines: stationary and movable. They are composed of respective number (from several dozens up to a few hundreds) of metallic segments located on skids usually directly on the ground. If the belt conveyor is movable, railwy rails are mounted at both sides to make its relocation possible by means of a special carrier. The construction resitance to ground of the particular belt conveyor segment is relatively high and equal to about 19 Ω. However, for the whole belt conveyor flight and when the construction of the segments are electrically connected in series by means of a flexible metallic cord welded on, the resultant foundation resistance does not exceed 1 Ω. If the electrical continuity is fulfiled (the railway rails connection is recommended since, the flexible cord is frequently damaged) both the ground parameters and the weather conditions do not influence the resistance of such the independent electrode.

3 Earth-fault current and potential distribution

Since, the mining machines, particularly composing the ETDc system, create the effective protective grounding therefore, they must influence both current and earth potential distribution in the ground under

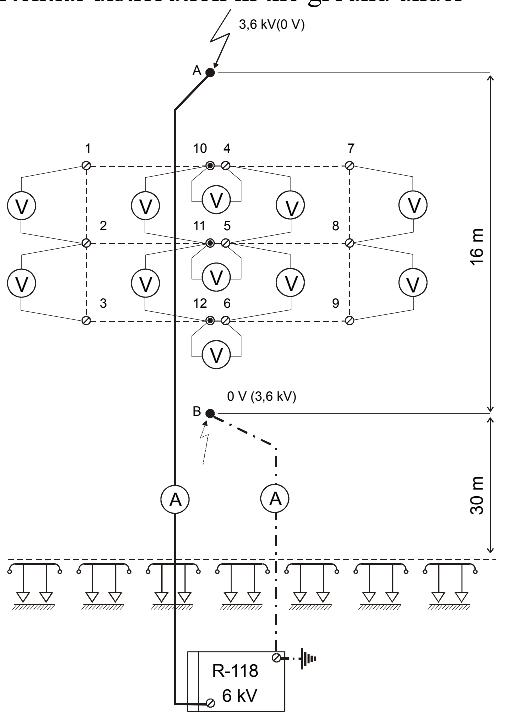

Fig 2. Sketch of measuring arrangement for testing current and earth potential distribution under the earth – faults close to the belt-conveyor; 1-12 – voltage probes (10, 11,12 located at the depth of 1 m inside the ground) A, B – current electrodes.

short-circuit conditions. It is obvious that some part of the earth fault current flows through their construction. For the MV power network with grounded neutral point via a low ohmic resistor it is the current passing through upper layers of the ground, metallic elements of the construction, and earthing conductors (PE) to the central grounding system of the main stationary transformer-distribution substation. To check efficiency of the belt conveyor as the functional earthing the respective investigations were carried out as it is seen in Fig 2. The earth-faults were performed by means of special rod current probes (A and B) which penetration inside the ground was equal to about 1 m. Their resistance values measured to ground were found to be around 120 Ω (R_A) and 70 Ω (R_B) respectively. The potential distribution was controlled around the area as in Fig 2 while, the voltage probes were located inside the ground at two depths 0.1m (probes 1 ÷ 9) and 1 m (probes 10-12).

Table 1. Potential distribution inside the ground around the short circuit (point A) 46 m far from the belt conveyor

Voltage measured between probes U_{ik}			Voltage U_{ik} calculated for assumed potential distribution		Conditions
			cylindrical	spherical	
-	V	%	%	%	-
U_{A4}	1200	-	-	-	Earth – fault current
$U_{4,5}$	22	100	100	100	
$U_{5,6}$	15	68	66.7	44.4	
$U_{1,4}$	11	50	34.2	28.4	I_A = 30.6 A
$U_{2,5}$	8	36.4	11.2	5.3	
$U_{3,6}$	0	0	5.3	1.7	
$U_{4,10}$	0	0	0	2.4	
$U_{5,11}$	5	22.7	0	0.3	
$U_{6,12}$	0	0	0	0.07	

Table 2. Potential distribution inside the ground around the short circuit (point B) close to the belt conveyor

Voltage measured between probes U_{ik}			Voltage U_{ik} calculated for assumed potertial distribution		Conditions
			cylindrial	spherical	
-	V	%	%	%	-
$U_{B,6}$	1440	-	-	-	Earth – fault current
$U_{5,6}$	30	100	100	100	
$U_{4,5}$	12	40	66.7	44.4	
$U_{6,9}$	8	27	34.2	28.4	I_B = 32,4 A
$U_{2,5}$	2	6.7	11.2	5.3	(-) negative
$U_{4,7}$	3	10	5.3	1.7	sense to the
$U_{6,12}$	(-) 5.6	18.7	0	2.4	others
$U_{5,11}$	3	10	0	0.3	
$U_{4,10}$	0	0	0	0.07	

First the investigations were carried out for the belt conveyor located far from the another mining machines to eliminate the influence of the different earthing systems and heterogeneity of the ground on the results. The investigated results of the potential compared to the calculations for both cylindrical and spherical distribution inside the ground, what is indicated in Table 1 and Table 2 respectively. They confirm the influence of the belt conveyor on the ground fault current distribution and therefore, on the potential in the ground as well. Current stream filament distribution deduced from this of the measured potentials is ilustrated in Fig 3 and 4.

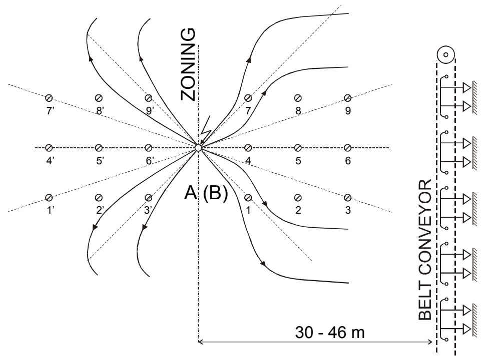

Fig 3. Diagram of the current stream – line at the upper layer of the ground under the earth – faults close to the belt conveyor; A(B) – current electrodes, 1-9, 1' – 9' – measuring points.

To find the current distribution (under following short-circuits the current values were fluctuated) as a reference voltage (100%) the voltage drop between probes located 4 m and 8 m far from the earthing point was assumed (e.g. $U_{4,5}$ for A-earthing in Fig 2).

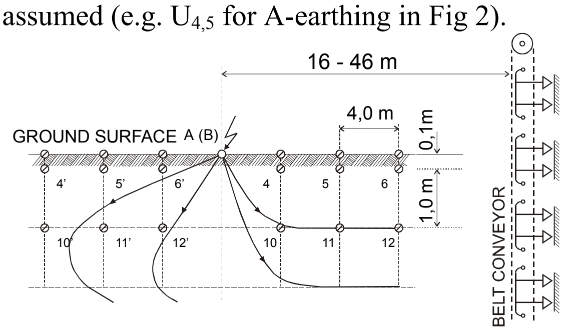

Fig 4. Diagram of the current stream – line inside the ground under the earth – faults close to the belt conveyor. A(B) – current electrodes, 4,5,6 – measuring probes at 0.1 m inside the ground, 10,11,12 – penetration of the probes about 1 m inside the ground.

Usually, under mining conditions a number of different machnes and electric equipment is located over a relatively small area, what can significantly influence the current and potential distribution. To check such the situation the investigations were carried out as in Fig 5. It was found that potential field around the place of the permanent ground fault is much more uniform and the current stream-lines are almost radial at the upper layers of the ground.

However, the field asymmetry is visible as well, from the side of the equipment of the smallest foundation resistance. In this case it was the belt conveyor PTB located relatively far (~ 100 m) from the shorting point (see Fig 5).

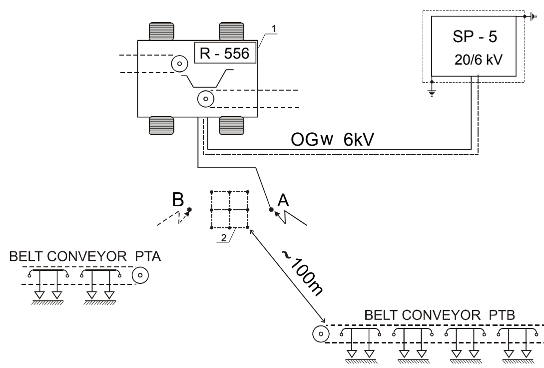

Fig. 5. Location of mining machinery under earth-fault investigations in 6 kV power network (A,B – current electrodes, 1-loading and driving station, 2-measuring area)

4 Conclusions.

- The investigations carried out in MV power networks confirmed that the maining machinery and electric equipment located directly on the ground can significantly affect the earth-fault current as well as related potential distribution at the area of its influence.
- Construction resistance to ground („foundation" resistance) of the mining machines is strongly related to size of the butting face and value of their force of inertia as well. Its value measured for large machines and movable transporters was around 1 Ω .
- Electrical connection of all track sections of the belt conveyor flight gives as a result the effective local earthing. Attachement of such the auxiliary electrode to the functional grounding of the central station through the construction and successively the earthing conductors (PE) produces desired results which meet requirements if about electric shock protection in MV power network. As a result the ground mat is provided what makes connection of another electrical equipment, like movable MV transformer-distribution and/or distribution substation possible.

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