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The danger of electric shock due to single-phase earth fault during a breakdown in portable conveyor belts

***Abstract**. The article presents the analysis and results of research on the risk of voltage shocks resulting from single-phase earth faults performed in a selected drive station of a sliding conveyor belt supplied with a voltage of 6 kV.*

Streszczenie.** W artykule przedstawiono analizę i wyniki badań zagrożeń napięciami rażeniowymi wynikających z jednofazowych zwarć doziemnych wykonywanych w wybranej stacji napędowej przesuwnego przenośnika taśmowego zasilanego napięciem 6 kV. **Zagrożeń napięciami rażeniowymi wynikających z jednofazowych zwarć doziemnych

Keywords: electric shock voltage, earth fault, sliding conveyor, earthing natural.
Słowa kluczowe: napięcia rażeniowe, zwarcia doziemne, przesuwny przenośnik taśmowy, uziom naturalny.

Introduction

Single-phase earth faults are one of the most often appearing disturbances in middle-voltage power networks [1]. The earth fault causes usually a direct hazard of an electric shock [2]. Proper detection and diagnosis of failing system components is crucial to efficient mining operations [3]. Electrical accidents may be the 4th leading cause of death in mining and are disproportionately fatal compared with most other types of mining accidents [4] The right implementation of high-resistance grounding of mine power systems reduces personnel hazards by limiting ground fault current and permits selective detection and clearing of faults. [5]

Mine power systems of conveyor belts in coal mines are exposed to a continuous change of location due to frequent changes in their location.[6] Sliding conveyor belt transport both spoil and overburden and those, cooperating with mining machines, are adapted for frequent relocation. Their specific work conditions force unique construction [6,7], including skidding. Often, for better stabilization of the conveyor system, the elements of the conveyor are connected by the rails, intended for the conveyor's movement. Such a construction, consisting of foundation skids and rails, placed directly on the ground, is a natural earthing system.

Usually, to power mining conveyor system, mining sheathed wires, powering individual drive stations, are used. These, usually run along the conveyor line and in stationary conveyors are suspended from the structure of the conveyor elements. The conveyor elements are on both sides joint by steel cables; they are usually welded to the structure and additionally connected by the protective conductor (PE) to the earth electrode of the central power station (20/6 kV).

This paper presents the results of the tests of metallic and resistance arcing faults and analyses, whether the metal skids of the conveyor elements, located directly on the ground and connected on both sides with the rail, are a natural earth electrode, protecting against electric shock.

Ground faults in the 6kV network as a cause of electric shock hazard

The electric shock hazards occurring during the operation of conveyor belt requires analysis of the operation of the network powering drive stations [8], and the determination of the actual hazard level requires the measurement of the prospective touch voltage on the accessible metal parts. Such tests may be performed only during short-circuit tests carried out in real conditions of the conveyor's operation. For operational reasons, it was crucial to check whether accidentally broken during the work, protective conductor or a breach of the cable structure would not cause the safety conditions.

A simplified diagram of the short-circuit current distribution to individual conveyor parts is in Fig. 1. There have been marked voltage drops and the place where the protective conductor connection was broken. For short-circuit tests, there have been selected the most frequently used driving stations of sliding conveyor belts working in the setting of operating systems powered from the 6 kV network with a neutral point grounded by the resistor (Fig. 2).

At the moment of shorting the active component of the earth current (I_{RZ0}) should be dominant. A grounding resistor (R_{Z0}) of 50Ω ensures it. It corresponds to the current of the metallic short-circuit at about 70 A. This value of current enables using of the overcurrent delayed ground-fault protection, operating selectively in this network configuration. In accordance to the applicable standards ([9] and [8]) in AC installations with a voltage higher than 1 kV, the permissible values of shock voltages, with a time of shock current flow over 1s, should not exceed 80 V [10].

Values of shock voltages depend on the ground-fault current and the efficiency of grounding of the power station and individual parts of the conveyor belt. In the case of active connection of all available metal parts with the central grounding of the power station by PE conductors, theoretically, there can be achieved the lowest risk of electric shock. However, in mine conditions, ensuring a permanent connection of all metal parts of the conveyor belt, especially the sliding one, is inconvenient and expensive.

Mine services take care of the best possible connections. However, because of work around the conveyor as well as the conveyor itself, it often happens that such connections are broken. Additionally, current distribution in the case of a single-phase ground fault is not the same in all conditions [11]. It depends on the design of the conveyor's mechanical system, its length, the variability of the metal skids and the effectiveness of rail fastening to the skids and other external factors (change of soil resistivity due to weather conditions and diversity of the foundation layers). In such configuration, the values of the shock voltages (touch) depend not only on the place of grounding but also on the share of individual resistances (Fig. 2). The resistance of the drive station foundation and the resultant earth resistance of the conveyor elements (skids and rail) create the circuit of the natural electrodes.

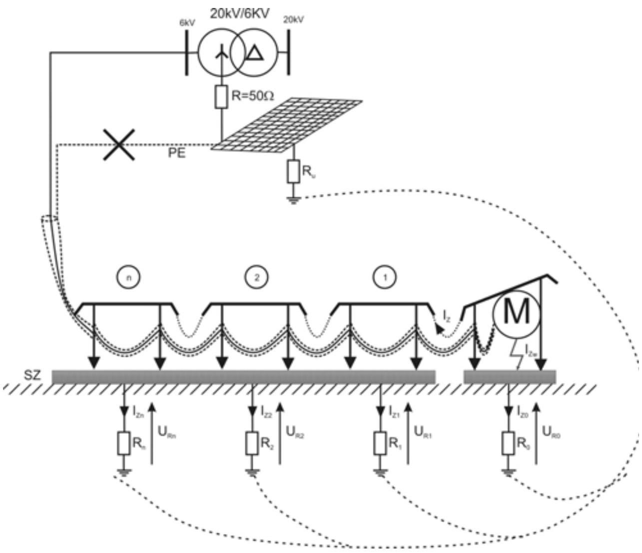

Fig.1. Simplified diagram of the earth faults current distribution during a short circuit to the conveyor part taking into account the break in the *PE* conductor; R_u - resistance of the earthing of the central power station; $R_0, R_1 \ldots R_n$ - resistance of the foundation of the power station and partial resistances of the rail (*SZ*) of the conveyor, I_{zw} - short-circuit current, $I_z, I_{z0}, I_{z1} \ldots I_{zn}$ - short-circuit currents flowing in the PE conductor, through the station foundation resistance and partial ground resistances of the conveyor's rail, $U_{10} \ldots Ur_n$ - shock voltages on the construction of metal power and transfer station and other conveyor components.

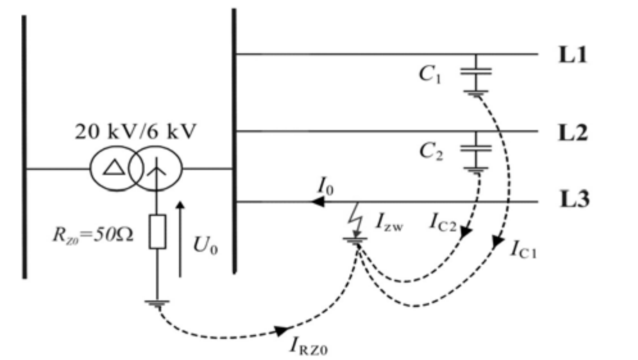

Fig.2. Diagram of current distribution in a 6 *kV* network with a neutral point earthed by a resistor (R_{Z0} ~ 50 *W*). *Izw* - current in the place of a ground fault, *IC*1, *IC2* - capacitive current of healthy lines *L*1 and *L*2, I_{RZ0} - active component of earth fault current, I_0, U_0 - zero-sequence current and voltage in a shorted line

The current distribution shown in Fig.2 shows that the current at the fault location is the total capacitive current of the sheathed mining cable and the active current enforced by the R_{zo} resistor in the star point of the 20/6 *kV* transformer.

Testing of shock voltages during ground faults performed on sliding conveyor

To determine the impact of natural ground electrodes and the conveyor's construction on the values of the shock voltages during single-phase earth faults. Short-circuit tests and measurements were carried out on a sliding conveyor supplied from the 6 *kV* station. Short circuits were performed, taking into account a few locations (Fig.3):

a) on the 6*kV* switching station,

b) a temporary grounding in the form of an electrode placed near the station powering conveyor,

c) on an isolated site at the construction of the conveyor,

d) on the conveyor in the section directly connected to the transfer station,

e) at the transfer station.

Ground faults were made for:

a) single phase metallic faults:
- to the construction of the power station,
- to the construction of the selected, galvanically connected, conveyor parts,
- to the construction of the selected conveyor parts, isolated from each other,

b) single-phase arcing and resistive faults made directly to the ground.

Fig. 3. Diagram of the location of single-phase metallic arcing and resistive faults made on a sliding conveyor

For the measurements, a test circuit consisting of a current transformer (*PJ*) with a current ratio of 150 / 5*A* equipped with a high-voltage fuse (WBWM-1-6 / 100) was used. The connection of the test circuit with the selected point of ground fault was a 6 *kV* high voltage cable. During short-circuit tests, both the zero-sequence voltage U_0 and zero-sequence current I_0 were measured and automatically recorded in the *R* 6*kV* power station fields. The simplified electrical diagram of the test circuit is in Fig. 4.

During the tests, using a measuring card and analogue meters, there were recorded:

a) the current flowing directly at the fault location (Fig. 4a),

b) shock voltages at the selected locations of the available metal parts of the tested devices (Fig. 4b) (probes located at a distance of 1 meter from these devices) and

c) potential distribution in the ground in the vicinity of a resistive earth fault.

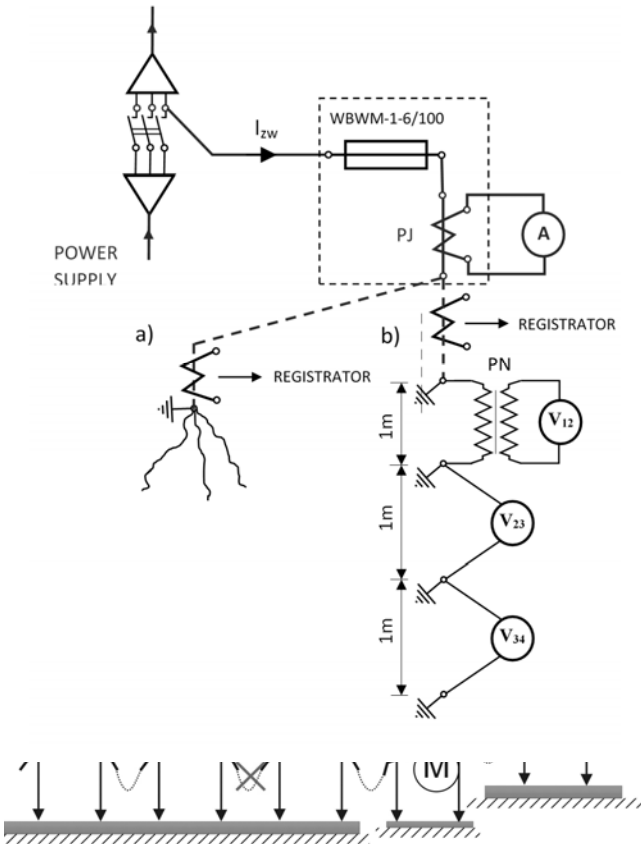

Fig.4 The simplified electrical diagram of the test circuit

In the case of measurement of potential distribution in the ground, 6 kV voltage was applied directly to the probe placed in the ground. The tests were carried out under different atmospheric conditions in the following months of the full year from November to July. Each time, before the measurement, the ground resistivity in given atmospheric conditions and also the resistance of the tested conveyor foundation were measured before the measurement.

In the case of a metallic fault to the construction of the power station and/or the conveyor's drive station, connected efficiently with PE cables to the central earthing of the 20/6kV power station, the touch voltage is the smallest, because the fault current closes in the "short loop". However, this risk may be different during ground faults to the construction of a metal conveyor, when not all parts are directly connected to the station structure with the PE cable or, in the extreme case, when the PE cable breaks. Checking the effectiveness of earthing by foundation required carrying out appropriate short-circuit tests for different constructions of the conveyor (parts connected and unconnected by earthing cables, different positioning of the skids to the railway, etc.) and in different weather conditions (variable soil resistivity) in the whole year range.

Results of related measurements made on a sliding

The values of shock (touch) voltages were measured at the measuring points shown in Fig. 3 under weather conditions of spring, fall and winter. During metallic faults, regardless of the season, length and location of the sliding conveyor, the measured and recorded values of short-circuit currents, current I_0, voltage U_0 and shock voltages were similar to each other. An example of the shock voltages during a metallic single-phase short circuit is in Fig. 5 and Fig. 6. The drawings show that, in the case of the tested conveyor, the highest recorded value of the shock (touch) voltage did not exceed 6V.

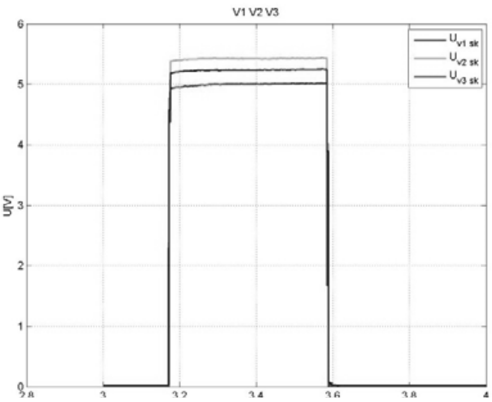

Fig.5. Waveforms V1-V3 during a metallic 1-phase earth fault to the construction of 6kV station on a sliding conveyor (summer)

There were performed metallic fault tests to assess the risk of electric shock, also to the "separated" (not connected with the construction of the station) conveyor parts (Fig. 3c). The parts attached to the metal skids were galvanically connected to the rails. The highest recorded values of shock voltage occurred when the soil was firmly dried (measurements were taken in autumn). Measured voltage values did not exceed 4 V (Fig.7). However, during arcing faults performed in spring on dry ground, the practical values of shock voltages did not exceed 35 V (Fig.8). One-phase faults, regardless of their type, were effectively switched off (after about 2 seconds) by current-delay protection.

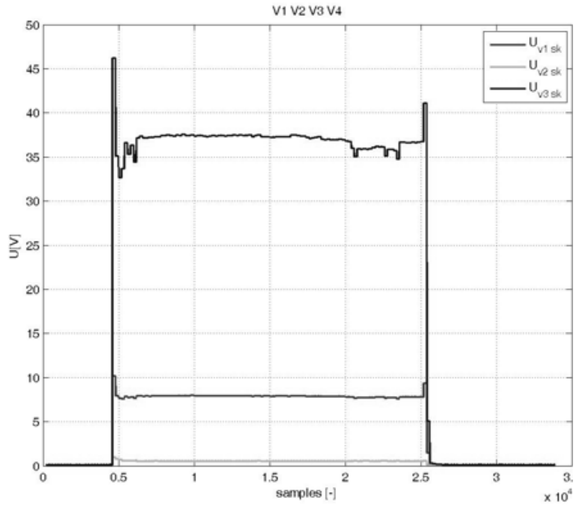

Fig.6. Waveforms V1-V3 during a metallic 1-phase earth fault to the construction of 6kV station on a sliding conveyor (performed in the summer)

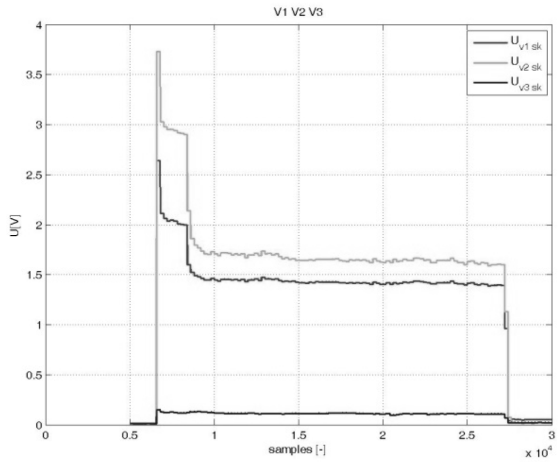

Fig.7. Waveforms of the expected voltage V1-V3 during a metallic 1-phase earth fault to the construction of 6kV station on a sliding conveyor (performed in the autumn)

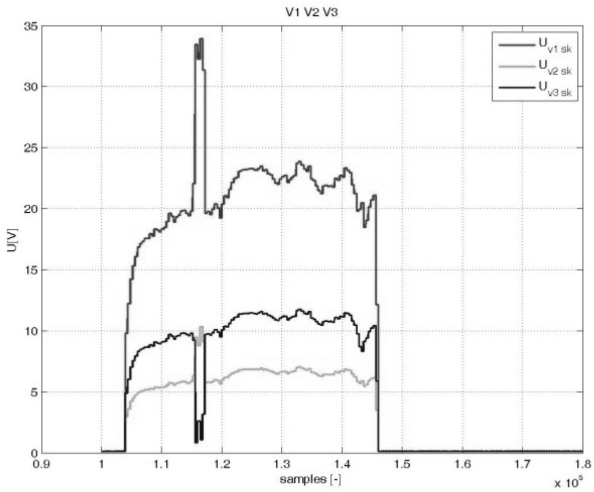

Fig.8. Waveforms of the expected voltage V1-V3 during a metallic 1-phase earth fault to the construction of 6kV station on a sliding conveyor (performed in the spring)

A comparison of the obtained measurement results, for a sliding conveyor, in all seasons, made with analogue meters is in Tab. 1.

Table.1. A summary of the results of measurements made on a sliding conveyor

Season	Soil resistivity ρ [Ωm]	Fault type	Earth fault current Izw [A]	Fault time tzw [s]	Expected touch voltages /potential distribution [V]
Autumn	115.3	Metallic	~65.0	2.08	1.5 – 7.0
		Arcing	17.0	2.08	4.0 – 7.5
		To the construction parts	67.0	2.08	4.4 – 50.0
Winter	103.0	Metallic	65.0	2.09	6.5 – 8.5
		Arcing	~8.0	2.09	0.1 – 2.0
		To the construction parts	~65.0	2.09	1.0 – 11.0
Spring	180.0	Metallic	~65.0	2.1	0.5 – 12.0
		Arcing	15.0	2.09	0.4 – 0.6
		To the construction parts	~65.0	2.08	1.0 – 5.0
Summer	82.1	Metallic	68.0	2.08	8.0 – 13.8
		Arcing	13.0	2.09	1.7 – 3.8
		To the construction parts	68.0	2.09	1.0 – 18.0

Conclusions

In a 6 kV network, supplying drive systems for sliding conveyor belts operating with a neutral point earthed by a resistor, there is a dominant influence of the active component of the ground fault current. For this reason, the current and voltage waveforms of zero components, during single-phase ground faults, are practically in phase with each other. This fact confirms the possibility of using uncomplicated earth fault protection. Measured, in 6 kV networks, values of shock voltages during the performed short-circuit tests (regardless of the atmospheric conditions resulting from the seasons) do not exceed the acceptable values in accordance to the applicable standards.

In addition, the carried out tests have demonstrated that the metal structure of the skids foundation (directly connected through the rail on the ground) is as a capable, natural earth electrode (of the tested five-hundred-meter sliding conveyor). The values of shock voltages in the absence of galvanic connection of the first three conveyor parts with the metal construction of the drive station (earthed through the PE cables) are the highest ones, and they are not dangerous in the tested object.

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