EXPERIMENTAL DETERMINATION OF A CURRENT OF GROUND CONNECTION IN THE MIDDLE VOLTAGE NETWORK IN AN OPENCAST MINE

Kiril Dzhustrov

University of Mining and Geology "St. Ivan Rilski", 1700 Sofia, justrov@mgu.bg

ABSTRACT. To determine the settings of relay protection from single-phase ground connection, an experiment was conducted in which the ground fault current was recorded on a conductor grounded on a rock mass and on soil. To determine the full current of a ground connection, the current of a metal ground connection was also recorded. The experiment was carried out in real conditions in an opencast mine and the results were compared with the theoretical ones. An assessment has been made of the possibility of setting relay protection from single-phase ground connection in opencast mines with high specific soil resistance.

Keywords: relay protection, single-phase ground connection

ЕКСПЕРИМЕНТАЛНО ОПРЕДЕЛЯНЕ НА ТОКА НА ЗЕМНО СЪЕДИНЕНИЕ В МРЕЖИТЕ ЗА СРЕДНО НАПРЕЖЕНИЕ НА ОТКРИТ РУДНИК

Кирил Джустров

Минно-геоложки университет „Св. Иван Рилски", 1700 София, justrov@mgu.bg

РЕЗЮМЕ. За определяне на настройките на релейни защити от еднофазни земни съединения е проведен експеримент, при който е регистриран токът на земно съединение при паднал на земята проводник върху скална маса и върху почва. За определяне на пълния ток на земно съединение е регистриран и токът на метално земно съединение. Експериментът е извършен в реални условия на открит рудник, като резултатите са сравнени с теоретично получените. Направена е оценка на възможността за настройване на релейни защити от еднофазни земни съединения при открити рудници с високо специфично съпротивление на почвата.

Ключови думи: релейни защити, еднофазни земни съединения

Introduction

Single-phase ground current in medium voltage grids in opencast mines are the most common failures. The reasons for this are the specifics of the operation of the electrical installations in the open mine - the supply of flexible cables for excavators and other electrical equipment, frequent transfer of the distribution line networks along with the movement of the mining operations, the influence of the environment on the condition of the cable insulation, conducting controlled blasts, etc. The consequences of the ground connections are manifested in prolonged periods of mechanisation downtime and in the development of contact and percolation stresses that are dangerous to the personnel.

Therefore, it is necessary to install relay protections against the single-phase ground current in medium voltage networks to quickly and selectively disconnect the damaged exit.

Problems with earth ground connections in the medium voltage electrical networks with an isolated neutral

In the event of ground connection, voltage and currents with zero sequence occur. The zero-sequence voltage is the same for the entire electrically connected network. Figure 1 shows the distribution of zero-sequence currents upon Earth-phase coupling of phase A from exit 1. In n, k, and m, current filters are provided with zero sequence. The filter at point n will show current $3I_{03}$ (Exit 3), the filter at point k will show current $3I_{02}$ (exit 2), and the one at point m will show current: $I_{0m}=I_{02}+I_{03}$.

Hence, follows the rule that the zero sequence current measured at the beginning of the damaged exit is equal to the sum of the zero sequence currents determined by the capacities relative to the ground of the entire network without the zero sequence current through the capacitance conduction of the damaged electrical exit.

$$I_{0m} = \sum_{1}^{n} 3I_{0n} - 3I_{0повр\ изв} \qquad (1)$$

When the network has multiple branches, this rule can be used to detect the power line with the ground connection. In the branch with the ground connection, the largest zero-sequence current flows and this acts as the principle of action of the non-current current-earth protections. The zero sequence currents in the non-damaged phases (terminals) are small, determined only by the capacity of these branches relative to the ground.

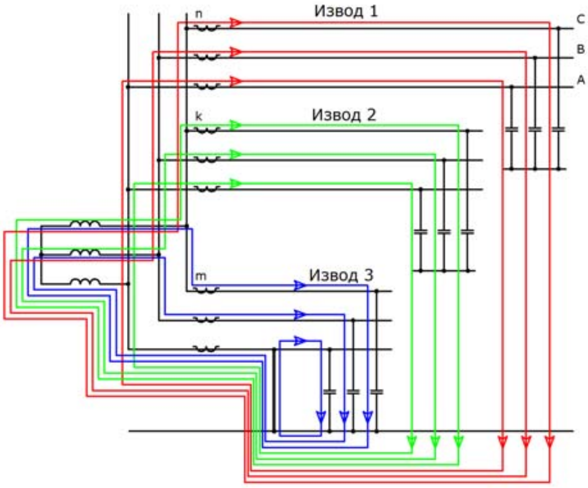

Fig. 1. Distribution of currents in a metallic ground connection

Experimental research

The occurrence of ground connections in networks with isolated star center is often followed by large values of the transient resistance at the fault site. The current of the ground connection may decrease below the cost of ground protection - it becomes ineffective. Another reason for lowering the current of the ground connection made mainly from distribution lines is that their capacity, compared to the ground, is 30 times lower than the cable line with the same length. The 6kV networks of *Asarel-Medet JSC* and the *Elatzite* Mine Complex can serve as an example.

The total length of the stationary cable network to the winding 1 of the transformer of *Asarel-Medet JSC* determines the capacitance current Ic=30.67A. The ratio of the common lines of the cable to the airline is 1.85. The air of the grid creates here a capacity current below 1A (Перпелицев и др., 2013). In the *Elatzite* Mine Complex, the ratio of the common lines of the cable to the air is 3.05. The total capacity current Ic=33.25A was determined mainly by the cable network, with only 0.18A of it being due to the air power lines (Стоилов и др., 2013)

In practice, in the normal mode of operation, not all power lines are included, and the earthing current is lower. For example, for the *Elatzite* Mine Complex, a working regime regarding the capacity earth current is considered that excludes the whole the second feeder from the CRP to KET1, KET3, GTL, and MKTP. Under these conditions, the minimum capacity current Ic is:
min Σ Ic = 22,07 A.

It should be noted that the above mentioned currents are in a "metal" ground connection. In an opencast mine, ground connections are most often due to mechanical failure in the distribution and cable lines. The heaviest case is the breaking of a distribution line and its fall to the ground, whereby the ground connection will be a function of the length of the free-laid conductor on the ground and the transient resistance at the site of the damage.

To explain the phenomenon, an experiment was carried out in which the ground connection was a conductor grounded on a rock mass and on soil. The measurements were carried out at the end of "Open Pit 4" of the *Elatzite* Mine Complex. Experimentally, the ground connection the current at two points of stationary power line "Open Pit 4" was shot:
- point №1 was at a distance of 1800 m from CRP.
- point №2 was at a distance of 1000 m from CRP.

The current of the ground connection was determined in 2 cases: a AC-25 conductor laid on the ground with a length of 50m; and direct connection of one of the phases with the stationary electric current (AC-95) with lighting protection cable (AC-50)

At measurement point 1 (Figure 2), a 6 / 0.23 kV transformer was connected to the power line to power the camcorder. Therefore, the current of the transformer was also recorded in the ground connection circuit. In this measurement, the conductor was laid on a rock mass. Upon completion of the transient process with the transformer currents, the earthed current oscillated within the range of 1.9 ÷ 2.3A due to the occurrence of electric arcs between the free-lying conductor and the ground.

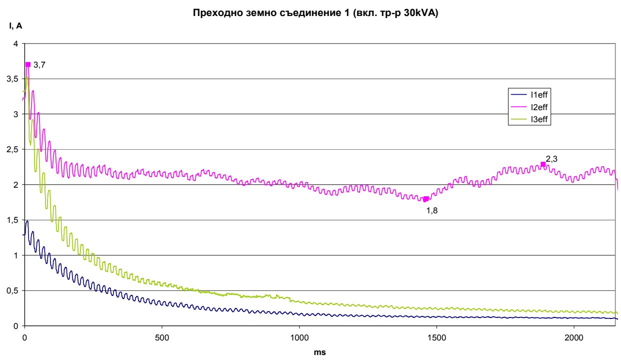

Fig. 2. Electric currents when turning on transformation with transient ground connection at point 1

When measuring at point 2 (fig. 3,) the conductor was laid in a rock mass and soil. The larger part of the conductor lay on soil.

Fig. 3. Current in a transient ground connection at point 2

In figures 4 and 5, the metal ground connection is shown at point 1 and point 2, respectively.

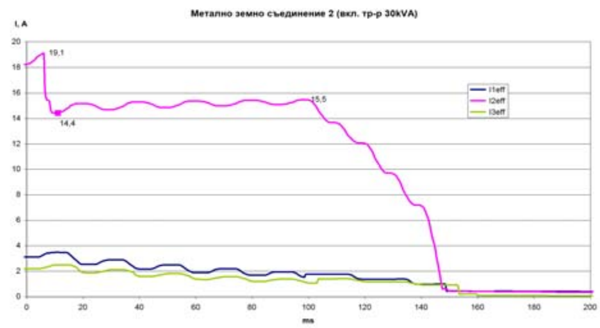

Fig. 4: Current in metal connection at point 1

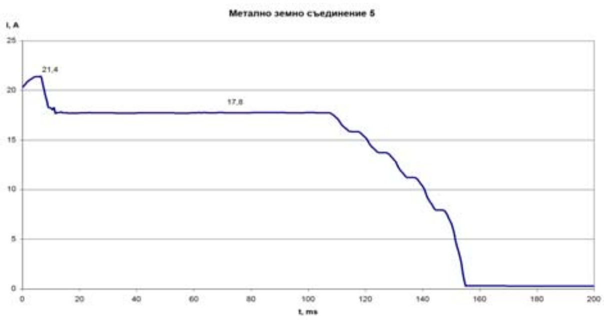

Fig. 5. Current in metal connection at point 2

Table 1.

Point of measurement		*ip*,A	*I"*, A	*I3*, A
№ 1	Ground connection laid on the ground	10.2		2.3
	Ground connection connected with lightning protection cable	103.4	19.1	15.5
№ 2	Ground connection laid on the ground	18.1		9.3
	Ground connection connected with lightning protection cable	52.4	21.4	17.8

Definition of Table 1 as follows:
i_p - peak value of the current in ground connection;
I" - superconducting component of ground connection current;
I3, - determined current of the ground connection.

During the experiments, all the conclusions of the CRP were included, which implies the registration of the maximum capacity current for the 6 kV network of the mine. It should be noted that this value is less than the value calculated by cable capacity data due to:
- the resistance of the lightning protection conductor;
- the transient resistance at the connection point of the phase conductor with the lightning protection cable;
- the resistance of the grounded installation in the CRP;
- the possibility that some cables were not under voltage during measurement.

For the calculation of the current $I_{зр}$ of unspecified earth-fault protection, it is necessary to reset the own capacity current of the exit I_c with the impact coefficient K_y taking into account the following:

$$I_{зр} = K_{отс}.K_y.I_c \quad (2)$$

The impact coefficient depends on the type of network and is theoretically in the range between 1 and 2. From the studies conducted for the particular mine, K_y = 1,2.

Inevitably, powerful motors and transformers generate zero sequence currents, which can lead to a malfunction of the relay protection. It is necessary to de-energise from these currents by introducing a certain time lag of output t зр:

$$t_{зр} = (0,1 \div 0,5)s \quad (3)$$

In a study by Stoilov and Dzhustrov (Стоилов и др., 2013), it was found that engines with a continuous start-up process generate zero-sequence currents and voltages only in the start-up phase, and that at 0.1 second from the start, I_0 does not exceed 10A.

The start-up processes in transformers are characterised by longer zero-sequence current generation and are presented in Table 2 (Стоилов и др., 2013):

Table 2.

Power, кVA	**Iп/Iпх**	**$T_в$, s**	**I_0, A**		**T_0, s**
			t=0	**t=0,5s**	
1000	22.0	2.0	111	8.3	2.0
630	26.3	1.8	35	1.6	1.4
400	27.2	1.4	38	1.3	1.3
250	32.3	1.5	35	0.5	1.4

When a metal ground connection occurs, a transient process (Figure 6) defined by the capacitive conduction of the power line to the ground is clearly visible. After about 10 ms, a sustained current, also containing higher harmonics, is established.

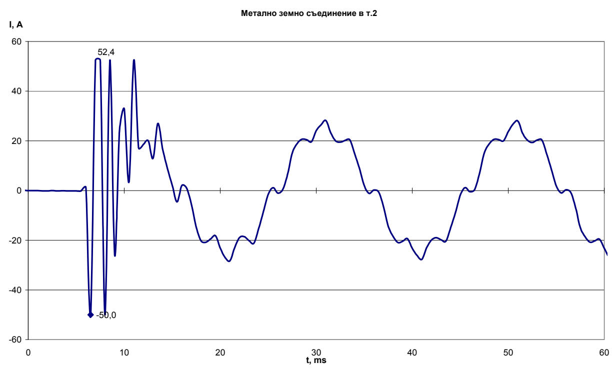

Fig. 6. Momentary values of the current in metal ground compound in point 2

The development of the transition process is similar at point 1 (see Figure 7):

The duration of this process is also about 10 ms, and the maximum amplitude of the shock current depends on the amplitude of the voltage at the moment of the ground connection.

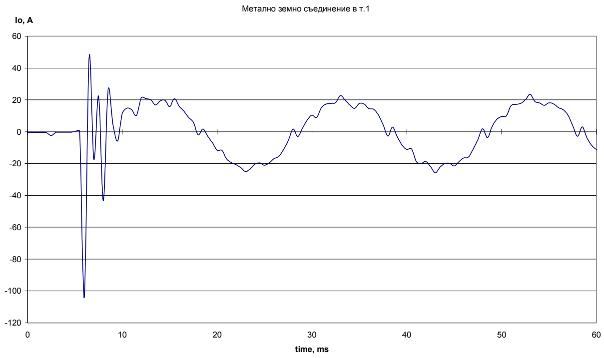

Fig. 7. Momentary values of the current in metal ground compound at point 1

Conclusions

1. In opencast mines, the earth's compounds usually occur through a significant transient resistance

2. The established ground connection is commensurate with the magnitude of the current with zero sequence when switching on transformers after 0.5 s

3. For open pit conditions, it is necessary to introduce at least two steps of protection from earth compounds, if the latter is unspecified.

4. The sensitivity of the protection is determined by (2), with the minimum protection delay time being 0.5÷1.0 s.

5. The setting of the gross level of ground connection protection is made by providing a sensitivity coefficient for a metal earth connection 2, which is

$$I_{зар2} \leq \frac{I_{мзс\,\min}}{2},$$

when $I_{мзс\ min}$ is the minimum current of a metal ground connection determined by the minimum working configuration of the power grid. The time delay of this degree is determined by the transition process when a ground connection occurs (Figure 6) and can be considered from 0.02 to 0.04 s.

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