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Detection of earth faults in electric power cables by analyzing changes in the short-circuit resistance

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Paper presents method of earth faults detection in electric power cables based on measurement and analysis of the short circuit resistance value in transient under mechanical bumps exerted on the faulty cable line during detection procedure. Discussed investigated results and formulates conclusions for use in practice.

Keywords: *electric cable, earth fault, detection method.*

Introduction

Effective ground fault detection and fast clearing in mine supplying cable network of both LV and MV is of great importance in view of both economic issue as well as safety requirements (hazard of fire and/or explosion in methane and coal dust environment). Commonly use methods and devices in electric power networks can not be therefore directly adapted to working conditions of underground mines, where such, aspects have to be carefully considered like: onerous microclimate of coal mine, specific environmental conditions and safety requirements that have to be met. One has to keep, in among other, elevated temperature (up to 45 ^{o}C), high humidity around 95% (at 45 ^{o}C), exposure to unexpected mechanical disturbances (shocks, vibrations, bumps) cramped spice, high noise level, insufficient lightning and necessity of limitation of a single phase short circuit current value as much as possible [2, 3]. As a result there is urgent need to develop new methods and to employ reliable protection devices applicable under underground coal mine conditions of operation.

Paper presents suitable method and arrangement developed by authors to detect high resistive earth faults in electric power cable lines used in mine, discusses preliminary laboratory test of investigations.

The project is realized by consortium companies and supported by Polish governmental institution –The National Centre for Research and Development. The project consortium consists of research institutes (Institute of Innovative Technologies EMAG, Tele and Radio Research Institute, Central Mining Institute GIG-KD "Barbara"), Silesian University of Technology and a private company MARTECH PLUS. The main objective of the project is improvement in work safety at coal mines.

Single phase ground faults in mine cables and ways of their identification

Simple phase ground faults that occur the most frequently in practice (around 85% of total faults in electric power networks — not only in mines) are particularly difficult to localize due to high short-circuit resistance value and related small fault current to measure efficiently. Commonly used methods basing on increasing discharge power value through faulty place to around 0,5—1 kW (forcing electric arc discharge) is in mines not acceptable. Therefore

T a b l e 1. Leakage earth resistance (maximum value) that must results in interruption of power supply in low voltage network

Rated voltage, V	Tripping (setting) resistance value, *k*Ω	
	Central protection (on-line)	Blocking protection
1000	**36,0** (30)	**60,0** (50)
500	**18,0** (15)	**30,0** (25)
230	**8,4** (7)	**18,0** (15)
133	**8,4** (7)	**18,0** (15)

T a b l e 2. Setting resistance value for central ground-fault protection in medium voltage network

Rated voltage, kV	**Setting**
$1 < U_n \leq 3{,}3$	220 kΩ ± 20%
$3{,}3 < U_n \leq 6$	360 kΩ ± 20%

the ground fault location in underground cable lines is based mostly on control of their insulation resistively value. Sometimes inductance or capacity value to the ground is controlled as well; it is called a rough localization of a faulty place. Usually two systems are employed: central leakage protection and local earth leakage protection. Basic physical parameters taken into account for leakage protections are: setting resistance value (table 1 and 2) and operation time provided that long lasting fault current is not higher that 25 mA.

Therefore, if only the isolation resistance value (to the ground) is found to be lower, the electric supply is immediately disconnected by the central leakage protection and further precise fault localization in the cable is performed under dead (no load) conditions. One of the useful method that can be used in underground mines is an impulse reflection method (IRM). However, the wave propagation speed along the cable line under test is in the range of 160—250 m/s and is not constant in time. Besides, it is varied during cable ageing and under influence of humidity and/or temperature fluctuations. However, interpretations of received (reflected) waveforms parameters without knowing topology of a grid is difficult. Therefore, effective detection of ground faults of resistance over a few hundreds ohms is almost impossible in practice.

Method based on measurements of variation of the fault resistance value and associated electromagnetic noise

Method developed by authors is based on measurement and analysis of variation of an insulation resistance value at the faulty point under the influence of external mechanical disturbances (bumps) exerted on the cable line under detection procedure [1]. To detect rapid fluctuations of the metering DC current (resulting from fast changes of insulation resistance value in transient between the cable cores and protection screen) a fast working ohmmeter device of a high sensitivity has to be employed.

The measuring equipment is able to indicate rapid changes in insulation resistance value between the cable cores and the protection screen. It is composed of a transmitter RAKn and receiver unit RAKo (fig. 2).

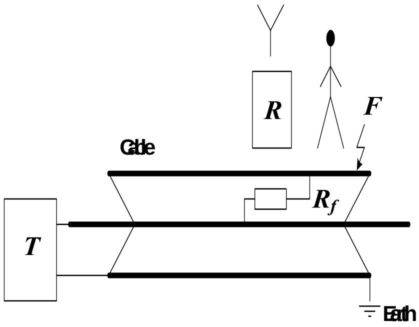


Fig. 1. Illustration of fault localization system (T — transmitter; R — receiver; F — external mechanical force).

Fig. 2. View of RAKn and RAKo units.

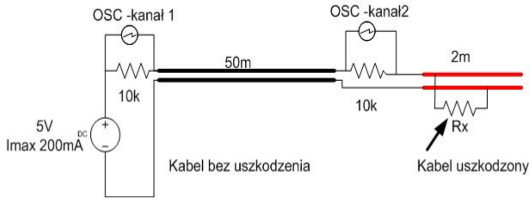
Both units are designed with use of the same microcontroller board. The transmitter that is used as the ohmmeter provides DC measuring current of a very small value (around 30 μA) and low frequency waves withacoustic frequency modulation for communication as well. The receiver in turn is equipped with antenna to detect maximum intensity level of electromagnetic radiation (cable tracing) and to receive data from transmitter. Communication link between the transmitter (ohmmeter) and the receiver is provided by a transmission channel using the cable under testing as a distributed antenna.

Laboratory test results

The fault location procedure requires cooperation of two persons and disconnection from supplying source of the damaged cable from the both ends. RAKn and RAKo units are battery powered — charging can be performed only within a safe area. The intrinsically safe battery has rated voltage of 12 V and capacity equal to 0,7 Ah. The system can be used in the temperature range between –0 ^{o} to +40 ^{o}C. The cases are made of glass fiber reinforced with polyester and are suitable for use under coalmine conditions (certified) — suitable for zones I and II. The leakage resistance is measured in the range of 0—300 kΩ with resolution of 100 Ω.

Investigations were carried out in circuit as in fig. 3. Measuring DC current value was about 250 μA for cable (~40m long) of total capacity equal to 20 μF. Observations of measuring signal at the beginning and at the end of open cable line have indicated negligible effect of distributed cable capacity on signal deformation (fig. 4).

Fig. 3. Sketch of testing system.



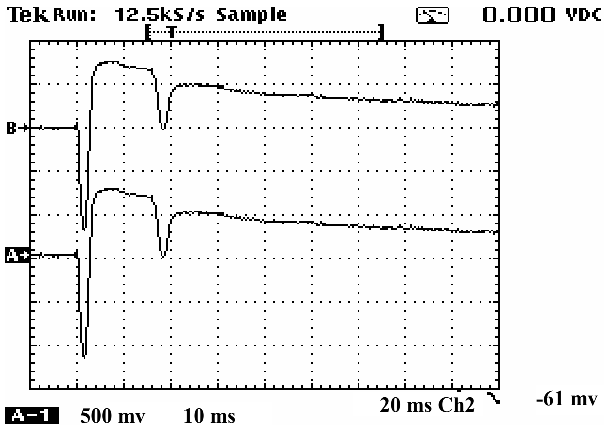


Fig. 4. Comparison of wave deformation in cable.

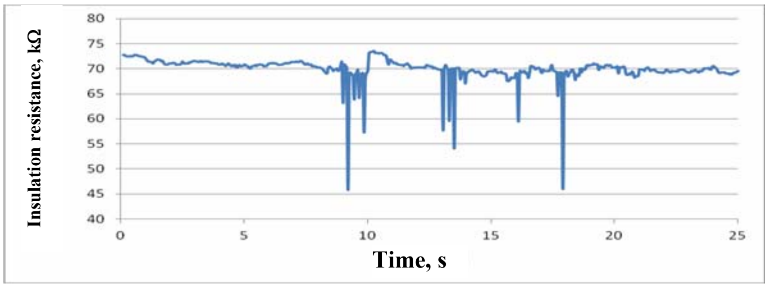


Fig. 5. Insulation resistance changes at the point of insulation damage under external force (bumps) applied.

By progressive reduction of measurement sensitivity or force (bumps) being applied one can find maximum effect (resistance fluctuations) just at the faulty (short circuit) point (fig. 5).

Conclusions

Localization of the faulty cable line in underground coal — mines with hazard of explosion (methane and/or coal dust) requires the use of special non-standard methods. The method developed by authors that is based on measurements and following analysis of leakage (ground fault) resistance variation under influence of external mechanical disturbance (bumps) exerted on the cable during measuring procedure is combined with detection of intensity level of electromagnetic radiation due to injected low voltage waves.

The advantage of this method is the possibility of detection of the high resistive earth-faults around 200—300 kΩ with resolution of about 1 kΩ and sufficient (with practical point of view) high accuracy of localization in power cable lines used particularly in underground mines. The developed system successfully passed laboratory tests and is now being prepared for research under working conditions of mine.

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Обнаружение дефектов в заземлении в силовых электрических кабелях

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Предложен метод обнаружения дефектов заземления в электрических силовых кабелях, основанный на измерении и анализе сопротивления короткого замыкания при кратковременных механических ударах (толчках), прикладываемых к дефектному кабелю в процессе испытаний. Обсуждаются полученные результаты и формулируются практические рекомендации.

Ключевые слова: *электрический кабель, дефект заземления, метод обнаружения.*

Виявлення дефектів у заземлюванні в силових електричних кабелях

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Запропоновано метод виявлення дефектів заземлення в електричних силових кабелях, заснований на вимірюванні та аналізі опору короткого замикання при короткочасних механічних ударах (поштовхах), що прикладаються до дефектного кабелю в процесі випробувань. Обговорюються отримані результати і формулюються практичні рекомендації.

Ключові слова*: електричний кабель, дефект заземлення, метод виявлення.*